METALLURGIA

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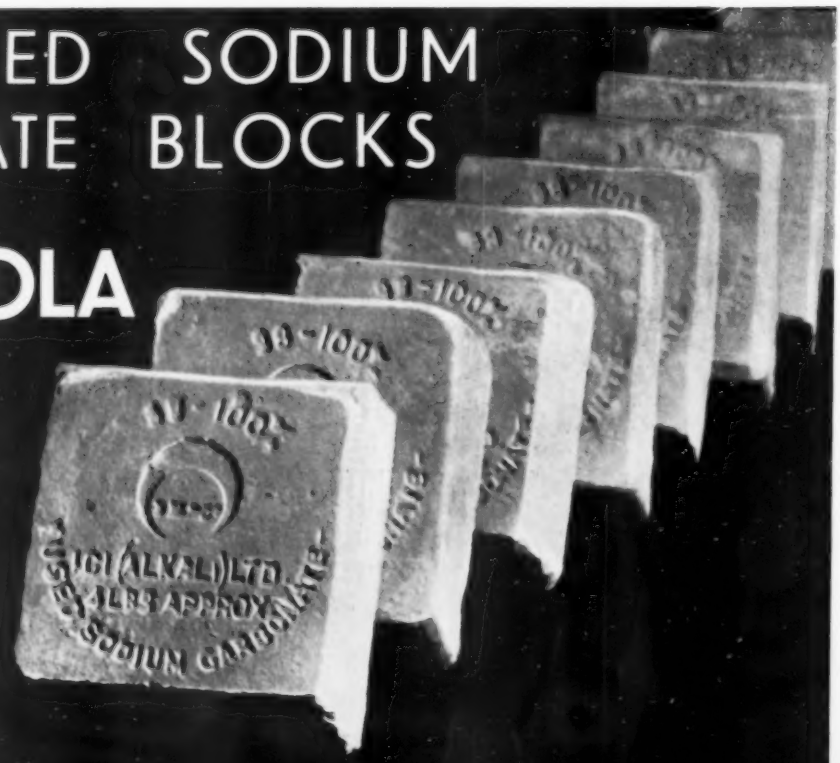

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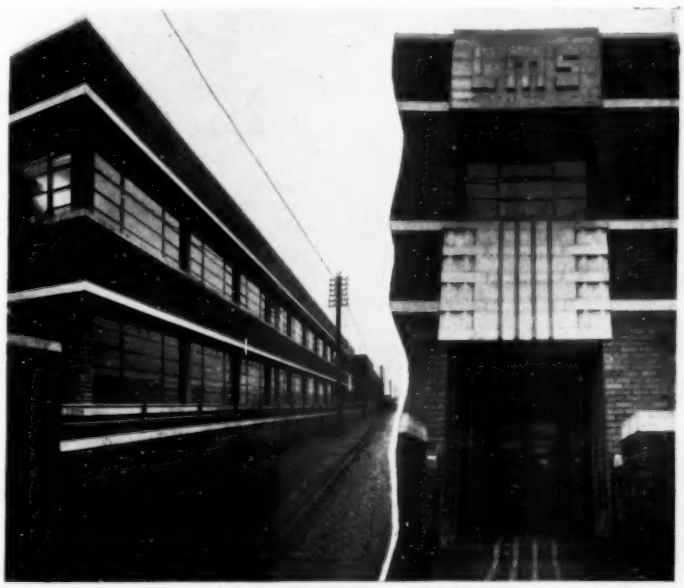
RAILWAY RESEARCH

A New Central Laboratory Opened at Derby

Science and research increase the fruitfulness of human industry and provide the fundamental source of progress. Appreciation of their value is increasing, and the opening of the new L.M.S. research laboratory at Derby is another indication of the desire for fuller knowledge of factors likely to improve the conditions of mankind, and with a view to the economic application of materials available.



Two views of the new research laboratory.

TO-DAY, we are realising that the great march of industrial progress depends essentially on research. Although coal and petroleum remain the main sources of power and heat, knowledge is being obtained in the less wasteful use of fuel and the advances which are being made in the percentage of the total thermal content of the coal which can be utilised is equivalent to an increase in the content of our coalfields. Thus, if there are no reasonable hopes of an increase in the sources of power, we have the confident expectation of greatly improved utilisation of the power produced. Gas and electricity, for instance, have shown themselves of inestimable value in the distribution of power and heat, and their utilisation in industry. The prospect before us, therefore, is not only of a more densely populated world, but of a world whose people demand more from it; involving increasing dependency on scientific and industrial research to provide adequate needs. Industries will continue to supply the products which we now make use of, but will do so by shorter and more effective processes and will in addition yield new materials of physical and chemical properties yet unknown to us.

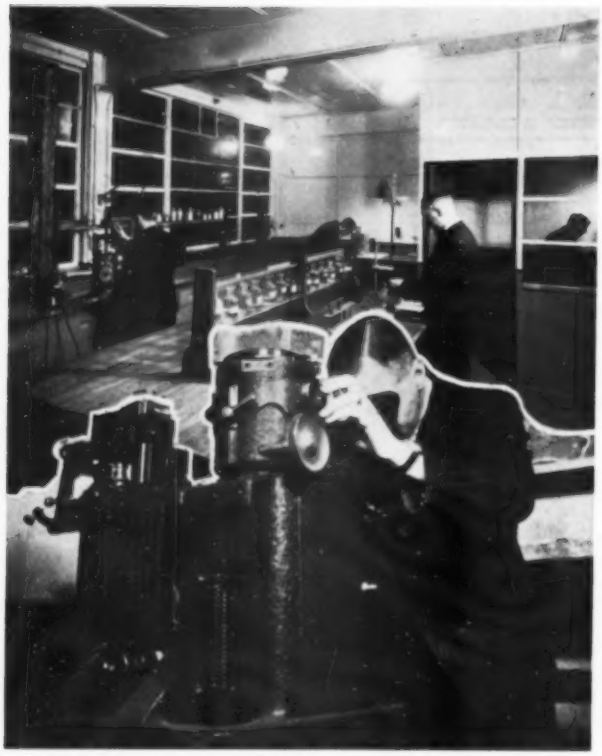
That science and research will offer to mankind the power of accomplishing greater progress than has yet been achieved is not doubted—the question is whether mankind will accept the results obtained. This point was raised by Lord Rutherford in a thoughtful address when he officially opened the new research laboratory of the L.M.S. Railway Co. at Derby, on December 10. There was a real danger, he said, that industries might tend to become more and more automatic in their routine, wherein the introduction of a new idea and a new process, even a new material, might prove disturbing and even almost catastrophic in its effect. The study and adaptation of discoveries and inventions in a research department might prove especially helpful in preventing this tendency. He emphasised the fact that the saving of 1 lb. of coal per mile of distance travelled on the railway, higher speeds or longer life of the rolling stock between repairs, were just a few of the factors of immense economic importance to a railway company and incidentally to the public generally.

Research and the L.M.S. Railway

The L.M.S. Railway is the largest commercial undertaking in the world. It has an authorised capital of £439 million and provides employment for 222,920 persons. It possesses 6,941 route miles of line open for traffic, 2,395 passenger stations and halts, 8,000 locomotives, 24,000 coaching vehicles, 270,000 merchandise and mineral vehicles, nearly 20,000 road vehicles, 45 steamers, 537 miles of canal and 31 hotels. In addition, it conducts extensive manufacturing undertakings in connection with the construction and maintenance of its rolling stock, permanent way, etc.

The business of a railway is to sell transport, and like all commercial undertakings its object is to provide the best possible service at the least possible cost. The function

A corner of one of the rooms in the paint and varnish section.



Chemical laboratory of metallurgical department (above). Vickers projection microscope in metallography room (below).

of scientific research is to help the Company's officers to solve the problems that arise in giving better service to the public and in effecting economies in operating and maintenance costs.

This new research department is the outcome of a steady growth from modest beginnings. Each railway company during the nineteenth century, established laboratories for the control of purchased and manufactured products, the earliest example being the Crewe Laboratory opened in 1864. They were not, in the early days, envisaged as research laboratories, but from time to time the pioneer enquiries of individuals resulted in sustained investigations of a research character. Similarly in other departments investigations of this type were not infrequently carried out by officers who were not content with routine trials of new materials and methods.

At the opening ceremony Sir Josiah Stamp stated that in 1930 Sir Harold Hartley was appointed Vice-President and Director of Scientific Research, and the company set up a permanent advisory committee including Sir Herbert Jackson, Sir Harold Carpenter, Sir Frank Smith, Dr. Rintoul, and Professors Egerton and Inglis—a body whose field of expert knowledge was indeed immense. The technical departments and officers of the company had since enjoyed the tremendous advantages of co-operation with this committee, and another outcome was the development of the present new research department, designed on a more scientific basis and equipped to co-ordinate and centralise the excellent work previously carried on in a detached way in many places. The day of haphazard and rule-of-thumb tests in unmeasured conditions was over, said Sir Josiah, and the day of controlled and directed experiment under arranged conditions had fully arrived.

The new laboratory effects a concentration of scientific resources and greatly increases the facilities for research, but it has never been the policy to render the L.M.S. research organisation independent of outside scientific assistance. The problems which may arise in the varied activities of a railway are so diverse in character that a very large staff of specialists would be required to deal effectively with all of them. The Department, therefore utilises to the fullest extent the national research organisation established under the Department of Scientific and Industrial Research; the Company is a member of six Research Associations; whilst, in addition, certain problems are allocated to the research laboratories at the Universities.

General Features of the Laboratory.

The Laboratory is adjacent to the Carriage and Wagon Works of the Chief Mechanical Engineer's Department, and has a frontage on the south-west side of the main Derby and London Road, with rail siding access adjacent. The site is about two miles from the centre of the town and three-quarters of a mile from the L.M.S. station.

The metallurgical section, under Dr. Hugh O'Neill, is concerned with investigations relating to the selection and manipulation by casting, forging, heat treatment, welding, etc., of metals used throughout the Company, and for the metallurgical examination of materials that have failed to give satisfactory performance in service.

In the furnace room facilities are provided for the melting, casting, and heat treatment of metals. Testing equipment for foundry sands is also available, and experimental welding work can be conducted if required. The furnaces comprise a 35 K.V.A. high-frequency spark-gap induction melting furnace complete with ingot moulds and a small gas furnace for heating the feeder heads. Ingots up to 18-lbs. weight of steel may be made, and their forging conducted in one of the smiths' shops of the adjacent works. A 2½ K.V.A. resistance furnace is also available for melting.

Heat treatment is conducted in a 14 K.V.A. G.E.C. furnace with "Electrflo" automatic recording temperature control, whilst a 9 K.V.A. G.E.C. furnace with automatic control up to 1,350° C. is provided for high-temperature work. A "Birlec" circulating air tempering furnace, taking 4 K.V.A. and thermostatically controlled from 100°–700° C. is also available, and weighing machines, quenching tanks, etc., complete the equipment.

For sand testing, Simpson-August mill, a "Speedy" moisture tester, sieve shaker for particle grading, bottle shaker for deflocculating clay, two types of gas permeability and ramming apparatus, and a compression strength-testing apparatus have been installed.

The equipment in the engineering room comprises standard machines requiring no detailed description. A Wohler fatigue-testing machine, and a modified Haigh electro-magnetic fatigue-testing machine are available, and a further machine for studying fatigue effects of interference fits is under construction. Ordinary tensile and compression tests are performed on a 15-ton Buckton machine of the single lever type, which can also be adapted for transverse bending tests and torsion tests. An Izod pendulum serves for general impact testing, and hardness can be studied on a 5,000 kg. Brinell machine, a Vickers diamond pyramid indenter and a Firth "Hardometer."

Apart from these machines, there is a variety of small apparatus of interest, including certain instruments designed by the Section for specialised field work. Amongst these may be mentioned a portable hardness indenter; a Herbert pendulum hardness tester; two extensometers; a sensitive stroboscope; a seismograph; an instrument for measuring rail wear, corrugation and dip at rail joints; a statistical deflectometer for recording spring deflections; and an acceleraometer for measuring maximum impact accelerations. A cathode ray oscillograph has also been obtained and is at present being adapted for use with an accelerometer.

In an adjoining room are two machines, designed by the engineering section, which are of special interest. In one of these, a wear-testing machine, two annular specimens can be rotated under forced peripheral contact at varying speeds and degrees of surface slip. The other machine, for studying the nature of the wear of rails and tyres, simulates a pair of wheels which revolve in contact with a rotating track. An electric motor drives the wheels and

(*Continued on page 38.*)

Special Apparatus Used for Testing Aluminium Alloys

By E. John Pike

(High Duty Alloys, Ltd., Slough).

A proper understanding of the mechanical properties of alloys is very difficult to obtain, but in recent years there has been much progress in determining tests which give a very good indication of the properties of a particular alloy. Development on these lines is a feature in the manufacture of aluminium alloy parts which are required to withstand high stresses, and in this article testing apparatus is discussed which has been designed to give an idea of the behaviour of materials under working conditions.

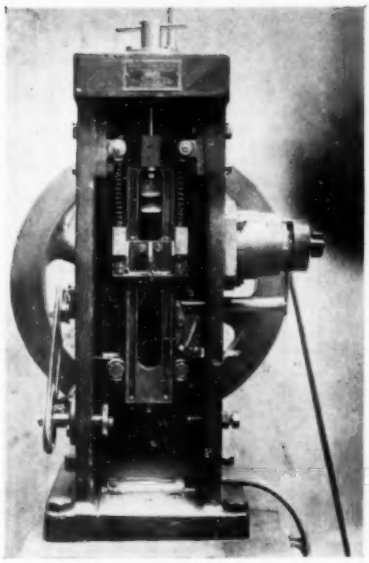


Fig. 1.—Amsler repeat impact fatigue testing machine.

APART from the usual forms of apparatus, such as the Universal type tensile, compression and bending, and the Wohler type fatigue endurance testing machines, which are used for most of the routine testing of all metals and alloys, there are many special types of apparatus designed to give some idea of the behaviour of materials under abnormal conditions. Obviously these machines are many and varied, and it is intended herein only to mention a few of those which have been used in the recent development of aluminium alloys. Perhaps one of the most interesting of these, especially in view of the applications which aluminium alloys are finding in the automatic machinery industry, is the Amsler repeated impact fatigue-testing machine.

Repeated Impact Fatigue Testing Machine

In this type of testing machine, Fig. 1, the test-piece is held securely at one end, while a hammer, transmitting a blow of known energy, is driven on a steel shoulder fixed on the opposite end of the test-piece, which is thus subjected to what may be termed a repeated tensional impact—*i.e.*, a blow tending to elongate the specimen in the direction of its longitudinal axis.

The results obtained from such a test are of great value in determining the relative suitability of various alloys for parts subject to repeated tensional stresses and impacts, such as are met with in most forms of modern machinery, particularly in connecting rods and links, pistons, shuttles, and other reciprocating parts, and form an interesting parallel to the bending fatigue stresses set up by machines of the Wohler type.

Results of tests carried out on a machine of this type are shown in Table I., and it is interesting to note that the alloy "Hiduminium" R.R. 53 B, with the higher elongation figure, but with the same yield and ultimate stress figures as R.R. 53, has a marked superiority in this respect. It may be added that it was largely due to tests carried out on this machine that the alloy "Hiduminium" R.R. 53 B was developed to meet the demand for a light alloy suitable for use in the form of high-speed reciprocating parts.

Bearing and Frictional Properties

In an effort to obtain data on the bearing and frictional properties of aluminium alloys at various elevated temperatures, the apparatus illustrated in Fig. 2 was designed and built in the laboratories of Rolls Royce, Ltd. In this machine, test specimens of the alloy under test are held in a chuck revolving at 545 r.p.m., which was driven through a swivel joint by an electric motor mounted above. This chuck presses the specimens against a disc of 0·5% carbon steel immersed in a bath of P 4 oil heated to various temperatures.

By means of a lever arrangement, the specimens are made to press against the steel disc with a pressure of 100 lb. per sq. in. The current required to drive the motor was taken to be directly proportional to the friction, and was charted for the various alloys against the temperature of testing. Fig. 3 shows a chart of the results of some of these tests.

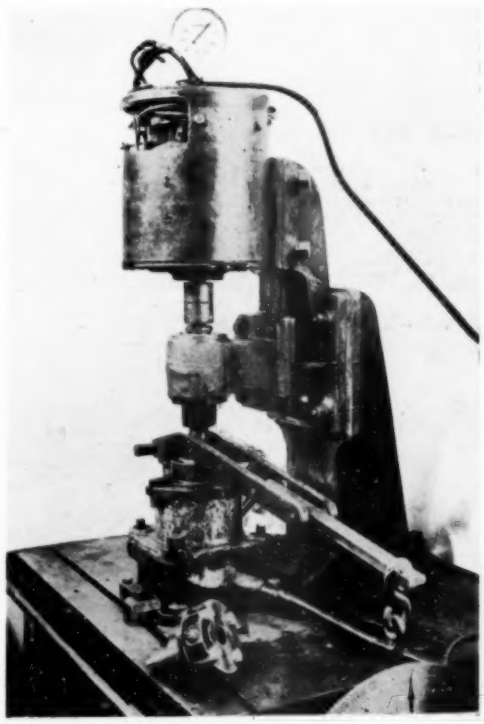


Fig. 2.—A Friction testing machine.

Rotating Fatigue-Testing Machine.

The "Whirling Rig," or rotating fatigue testing-machine shown in Fig. 4 is fundamentally of the Wohler family, and was designed to give an idea of the effects of casting and heat-treatment stresses in castings having abrupt changes of section.

The test-pieces for this machine are sand castings of the form shown in Fig. 5, being roughly in the form of a thin walled cylinder with heavy shoulders incorporated to introduce the effect of severe changes of section, with the resultant concentration of stresses.

Tests carried out on this machine, Table II., prove very illuminating. They show that an actual casting in

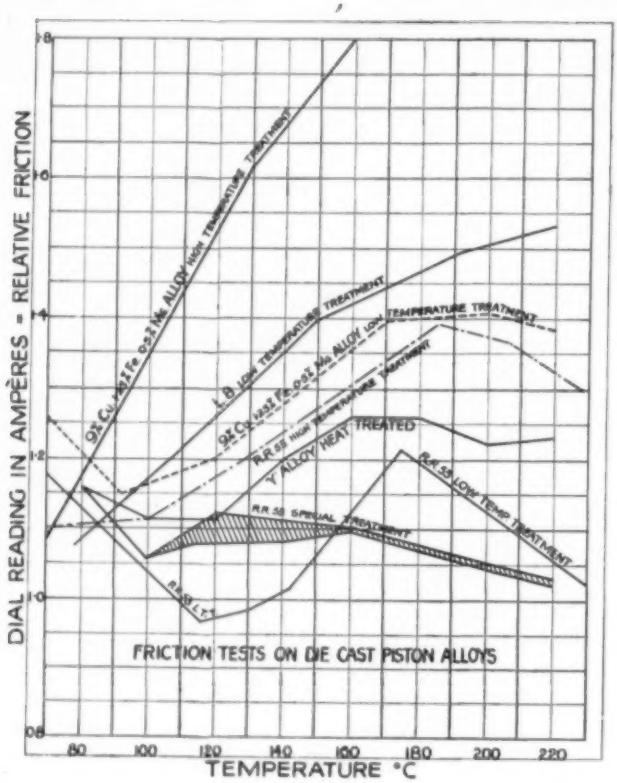

DIAL READING IN AMPÈRES = RELATIVE FRICTION
TEMPERATURE °C
FRICTION TESTS ON DIE CAST PISTON ALLOYS
Y ALLOY HEAT TREATED
R.R. 50 SPECIAL TREATMENT
R.R. 50 LOW TEMP. TREATMENT
PLAIN L 27

Fig. 3.—Chart showing results of friction tests on various cast alloys.

"Hiduminium" R.R. 50, after a low-temperature treatment of 10 hours at 170° C., and in this case with a tensile strength in the region of 13 tons per sq. in., has a higher resistance to fatigue than a high-tensile silumin gamma alloy casting, with a tensile strength of about 20 tons per sq. in., obtained only after a heat-treatment consisting of a severe quench from a solution treatment of 4 hours at 530° C., followed by an ageing treatment of 20 hours at 150° C. These results apply to tests carried out on actual castings, as distinct from test bars.

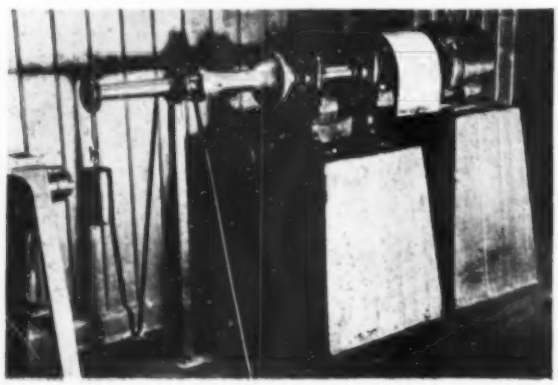
In this form of test the test-piece casting is rotated at 1,420 r.p.m., and is progressively loaded after running for 10 hours with a load of 200 lb., with an increase of 20 lb. every 2 hours until fracture occurs. Some further test results are shown in Table III.

Charting Internal Stresses

The question of internal stress is one which is of immense importance to both the manufacturer and user of aluminium to-day, as all high-tensile alloys depend either upon heat-treatment or cold work to produce maximum mechanical properties. In the case of heat-treatment of really high-tensile alloys, a severe quench from temperatures in the region of 500° C. is invariably resorted to, and it has been found in many applications that in complicated shapes internal stresses of some magnitude have been set up.

In such cases there are two alternatives—one is to take the line of least resistance and use a low-temperature treated alloy, in which case almost the entire section will have to be increased, with a consequent increase in weight and bulk—and the other course is to devise some means of charting the stresses so that modifications in design

Fig. 4.—Whirling rig fatigue-testing machine.



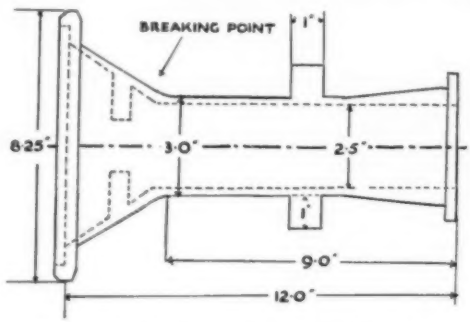


Fig. 5.—Sand Cast test pieces for whirling rig.

TABLE I.

AMSLER REPEATED IMPACT TEST.

Alloy.	Energy of Blow. 0·054 ft.-lb.	0·122 ft.-lb.	0·216 ft.-lb.
L 8	58,660	34,830	—
	58,670	13,550	—
	27,230	19,710	—
	58,650	22,610	—
	55,480	20,200	—
	53,410	28,110	—
Average	52,016	23,168	—
Aluminium Silicon	20,900	5,130	—
	37,520	4,100	—
	27,300	2,600	—
	29,450	1,973	—
	30,210	2,240	—
	28,110	3,740	—
Average	28,915	3,297	—
R.R. 50	507,260	155,750	2,860
	570,240	181,000	6,690
	562,740	178,450	2,940
	684,300	187,400	4,860
	459,750	108,960	3,470
	626,010	114,510	5,840
Average	568,220	154,345	4,443
R.R. 53	1,000,000	251,610	12,280
	Unbroken	296,330	7,510
	,,	254,980	9,300
	,,	314,200	11,510
	,,	228,150	10,840
	,,	213,710	8,490
Average	—	259,830	9,988
R.R. 53 B	1,000,000	320,300	50,040
	Unbroken	387,600	24,400
	,,	397,150	17,500
	,,	378,900	31,700
	,,	378,850	35,140
	,,	—	27,300
Average	—	373,000	32,000
"Y" Alloy	1,000,000	150,870	3,490
	Unbroken	111,320	3,520
	,,	130,210	2,780
	,,	121,400	4,540
	,,	140,100	3,800
	,,	139,110	3,720
Average	—	132,168	3,641

may be made exactly where required, and not to the piece as a whole.

A very optimistic school of thought is of the opinion that if a method of charting internal stress can be successfully devised, its result will be, not the total elimination of internal stress or its counteraction by thickening of parts of the section, but in the use of these stresses to counteract applied stresses. With the solution of this complicated and far-reaching problem in view, work was started some time ago in the laboratory of High Duty Alloys, Ltd., using a special form of X-ray spectroscope.

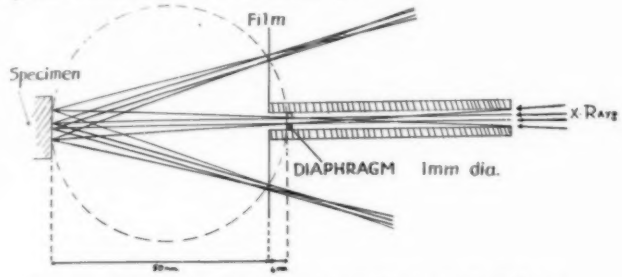


Fig. 7.—A section through the apparatus showing path of X-rays through the camera tube and diaphragm to form a slightly divergent beam which is reflected back on to the film through an angle determined by the formula $\lambda = 2d \sin \theta$ where—λ is the wave-length of the X-rays, d is the distance between the lattice planes, θ is the angle between the incident beam and the crystal planes.

TABLE II.

WHIRLING RIG OR ROTATION FATIGUE TESTS.

For test-piece, see sketch.

Revs. per min., 1,400. Tests run, 10 hours with 200 lb. load, subsequent loading being 20 lb. at 2-hour intervals.

Alloy.		Max. Load Applied.	Time.
Silumin Gamma as cast	(1).....	480 lb. ..	37¼
Heat-treated	(2).....	480 lb. ..	37½
R.R. 50 as cast	(1).....	520 lb. ..	40¾
Heat-treated	(2).....	580 lb. ..	46¾

TABLE III.

WHIRLING RIG TEST RESULTS.

Material.	Average Ultimate Load.	Total Hours Run.	Brinell Hardness of Specimens.	Condition.
	Lb.			
R.R. 50	590	48¾	80	Heat-treated
2 L 5	545	43	87	As cast
3 L 11	480	36½	67	As cast
"Y" alloy ..	490	38	104	Heat-treated
American alloy	480	37	80	Heat-treated

X-Ray Spectroscope

For the purposes of these experiments, a Phillips Metalix X-ray spectroscope fitted with a revolving back reflection camera was adopted to facilitate mounting on a tensile testing machine in the manner shown in Fig. 6, photographs being taken of the X-ray diffraction patterns of the test-piece subjected to various tensile loads. Several different forms of camera and radiation have been tried, and one of the most promising arrangements is that using a revolving camera and a diverging beam of monochromatic rays from a copper anti-cathode tube.

In this method the film is rotated to give interference patterns in the form of continuous circles, as opposed to the separate refraction images thrown by the relatively large crystals of aluminium alloys on a stationary film. The diaphragm is set at such a distance from the specimen as will throw the K a_1 and a_2 reflections into the sharpest possible focus on the film, which is placed 50 mm. from the specimen. Fig. 7 shows the arrangement diagramatically. As the exact "specimen to film" distance is essential for calculations of lattice dimensions, a standard piece of gold foil is fixed on the specimen during part of each exposure to provide a permanent record of the distance on each film.

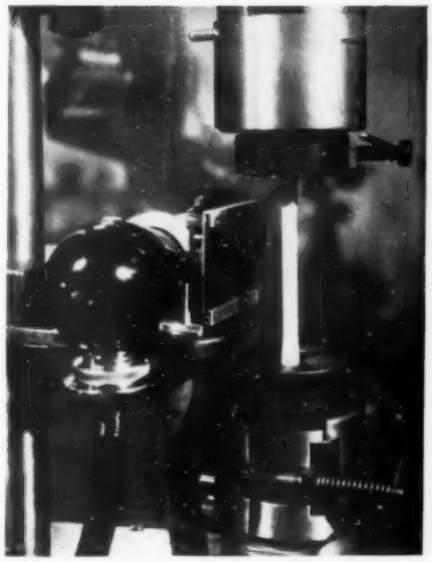


Fig. 6.—Showing method of mounting x-ray tube on tensile-testing machine.

The experiments unfortunately have not yet reached a stage where it is possible to give any figures, but the experiments show great possibilities of success.

In the early stages, using a stationary camera, it was seen that distortion of the lattice definitely took place with increasing stress. An exaggerated case where the specimen was subject to plastic deformation is shown in Figs. 8A and 8B.

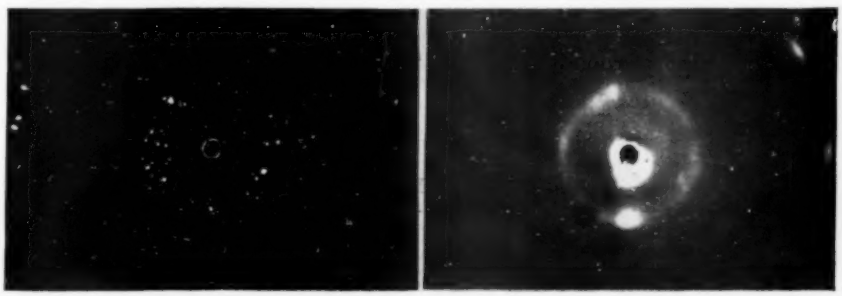
This method, in which it was hoped to measure the distortion of the lattice planes, was abandoned in favour of the present method, which is designed to measure the distortion of the lattice as a whole, as direction of distortion of the planes of different lattices introduced complications which made the process unsuitable for routine work.

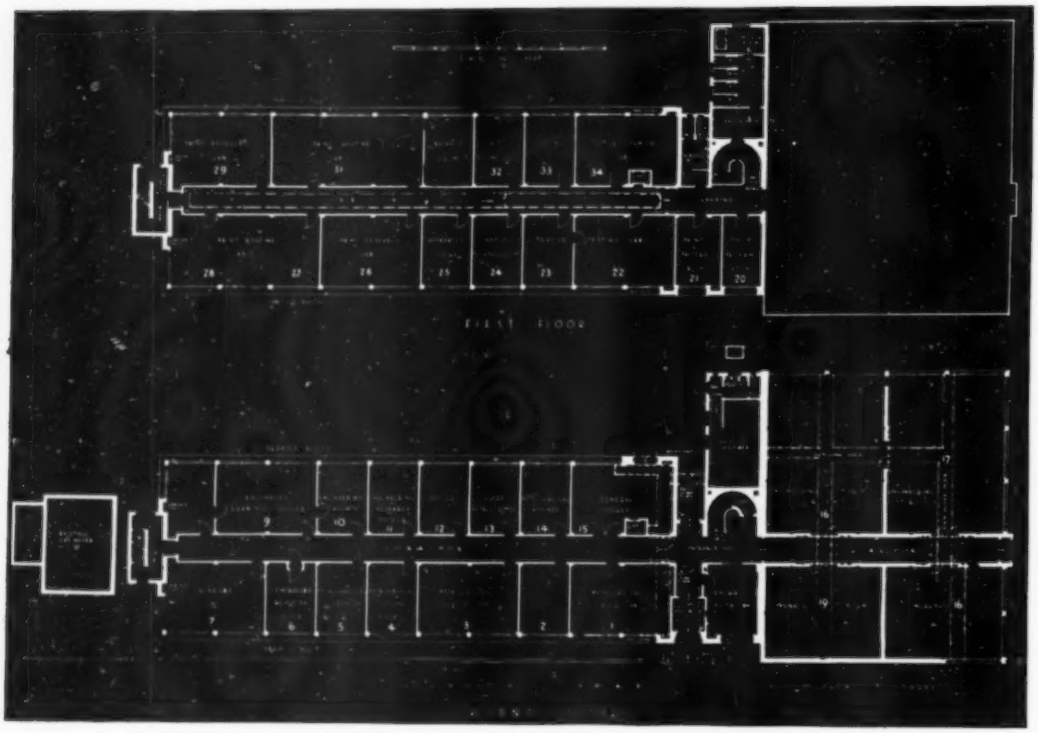
The biggest difficulty at the moment is that of measuring the diameter of the circles and the intensity of the interferences. Apart from personal technique in the development of films and adjustment of the X-ray apparatus, the measuring instruments available are either incapable of working with the high degree of accuracy necessary, or of so complicated and delicate a construction as to make them unsuitable for use in an industrial laboratory. This difficulty is receiving attention at the moment, and it should not be long before the apparatus is perfected, when it is hoped that great progress will be made.

Other investigators are carrying out very important work with the X-ray spectrograph in the study of corrosion and other important problems, and the future of this latest addition to the range of metallurgical instruments appears to have immense potentialities.

Fig. 8a.—Diffraction photograph of unstressed specimen.

Fig. 8b.—Diffraction photograph of specimen after deformation.





General arrangement of the various sections on the two floors of the laboratory.

Railway Research

(*Continued from page* 34)

power is taken by a generator driven by the track. In addition to studying wear problems, the machine is used for measuring wheel slip, and frictional and derailing forces under known applied conditions. Fatigue tests on helical and laminated spring plates are carried out on a machine lent by the Southern Railway.

The metallography room is equipped for the microscopial study of metals and alloys and for the preparation of photomicrographs. The latter are taken on a large Vickers projection microscope, and two dark rooms, one of which also serves the engineering section, are provided for photographic development. A Zeiss workshop microscope is provided for bench work, and there is the usual polishing and etching apparatus for the preparation of the specimens.

The chemical laboratory is intended for the preliminary chemical investigation of materials, though the majority of analyses required will be carried out in the main chemical laboratory in Calvert Street. A small balance room is provided, and, in addition to the usual equipment, a thermostatically controlled Hearson electric oven has been installed. The macro-etching of ingots and forgings is carried out in this room, as well as the production of fluxes, experimental electrodes, etc.

Apparatus is installed in a room set apart for the calibration of pyrometers and for determining the change-point temperatures of alloys. The main equipment is a Tinsley thermo-electric potentiometer with galvanometer and Cambridge chronograph. A 3½ k.w. "Silit" high temperature, and various electric tube furnaces are available for heating the specimens, whilst a "Hyvac" oil pump enables this to be done in vacuo. A Cambridge "thread" temperature recorder, temporarily in use on field tests, will also be available, and provision has been made for connecting it by leads to apparatus in any of the metallurgical laboratories or test rooms. At a later date it is intended to install a dilatometer and electrical resistivity apparatus.

A well-equipped workshop has been provided for the preparation of test pieces and for the manufacture of instruments, apparatus and testing machines. Though primarily engaged on work for the Engineering Section it is available for all other sections of the Research Department.

The Laboratory is a two-story building, and its main function is to test the qualities of the main materials used by the railway, particularly metals, woods, paints, varnishes and textiles of which large quantities are consumed by the Company, but, in addition, research work will be carried out with a view to improved service conditions.

Carriages for Soviet Railways

Soviet builders of railway rolling stock are planning to use more steel alloys in the building of railway carriages. The Soviet metallurgical works which have mastered the processes of producing steel alloys are expected to turn out sufficient quantities in the first half of next year to meet the new demands of the railway rolling-stock industry. Writing in a recent issue of *Za Industrializatsiu*, the Soviet engineer Travin, discussed some of the problems facing the railway-carriage building industry, paying special attention to the building of the new metal cars. Passenger carriages made of steel alloys are not only safer, but more economical, Stavin declared. Tests have shown that the front walls of the new 25-m. carriage are ten times as strong, the side walls 2·5 times as strong, and the roof 1·5 times as strong as those of carriages with wooden bodies in iron frames. Strangely enough, however, there is less metal used in this new carriage than in the wooden one, which Travin attributes to the better distribution of metal parts in the new carriage.

Metal carriages are now being designed for the electric suburban railways and for the Metro, the latter carriage being quite a new type. Plans are under way in the meantime for the making of 25-m. passenger carriages of silico-manganese steel at the Kalinin works by the end of 1936. This alloy is so light that its use will save from 8 to 10 tons of metal annually.

In his article, Travin also discusses the building of new types of railway trucks to replace the obsolete ones now in use. Tow-axle trucks must be abandoned for the more modern kind. With the adoption of large cars, he says, new types of large locomotives may be used for the first time to their full capacity.

METALLURGIA
THE BRITISH JOURNAL OF METALS.
INCORPORATING "THE METALLURGICAL ENGINEER"

British Trade and Industry

AT the close of 1934 we prophesied that the progressive spirit then manifest in British trade and industry would be cumulative and that in 1935 there would be further expansion in both home and foreign markets. The signs of recovery then evident have taken concrete form and, although final returns are not yet available, there is sufficient evidence to show that this year has been one of steady and continuous recovery, and a distinct feeling of confidence is noticeable in almost every British industry. While all sections of industry were engaged in overcoming the depression period the encouraging state of trade and industry now experienced in this country is due primarily to improvement in world trade generally. Almost everywhere there is an upward trend and, despite some disquietening factors, these have had a cumulative effect towards general recovery.

In the home market import duties have given manufacturers a considerable degree of security and substantial progress has been made in consolidating those industries that are vital to the industrial progress of this country. Much reorganisation has been effected and new plant has been installed so that production can be carried on efficiently and economically. Prices of raw materials have tended to rise during the year, but increased production coupled with improved quality of the finished produce has been possible in general without a corresponding rise in price. Improved technique in manufacture and greater production has offset not only increased raw material costs, but also increased personnel costs. In some industries manufacturers continue to regard import duties as an additional burden on their export trade. Problems have arisen which should not be beyond solution. The threat of the motor manufacturers to establish independent steel works is a case in point.

Reports from the industrial centres have remained encouraging throughout the year, in all the principal industries there has been improvement, and even the textile trades have shown more activity. The heavy trades have been well employed. The higher import duties imposed in the early months of the year removed uncertainty which was believed to be holding up new businesss for the iron and steel industry. This industry, in particular, has experienced a good year, production has increased steadily, and it is confidently expected that the returns for this month will emphasise the progress made. In addition to the iron and steel industry contributions to the improvement are made by engineering, coalmining, the automobile industry and shipbuilding. In all the shipbuilding centres there has been substantial improvement, and orders in hand have not been so large for many years. Clyde yards, for instance, have secured orders for new trading vessels valued at about £4,000,000, during the past month, and inquiries are on hand for several more ships. It is estimated that by next spring the Clyde shipyards will have over 400,000 tons gross of new tonnage on hand, which is not far short of the total tonnage built in this country last year. In addition, orders placed at Barrow, Birkenhead and on the Tyne indicate a considerable degree of recovery in an industry which suffered severely during the depression.

Although exports of manufactured goods have shown appreciable advancement the progress in trade is primarily due to expansion in the home market, which is quickly approaching saturation point Those districts that are mainly concerned in producing for the home market are doing well, but those which rely on overseas trade continue to experience difficult times. It was thought that the imposition of duties on goods coming into this country would have had a salutory effect in bringing about reasonable adjustment of conditions, instead other countries have shown a tendency to raise their import duties or to curtail imports by means of quotas. Yet it is the export trade which must be given special consideration if a substantial reduction in the number of unemployed is to be obtained in the near future.

One of the most promising developments this year is the new hydrogenation plant on the North East Coast. Despite the fact that coal is still the most economical energy producer, the modern trend of power production is toward the use of liquid and gaseous fuels in an ever-increasing degree. This gradual change is having considerable influence on the export of coal, but even in this country, well endowed with this valuable mineral, evidence of this change in the demand for more mobile fuels is quite apparent. The increase in the use of these fuels has resulted in the importation of large quantities of oil and petrol. It is to meet this competition that carbonisation and hydrogenation plants have been erected. It is extremely doubtful whether it would be possible to increase the demand for coal to that existing immediately before the war by this method, but the distillation of coal into liquid and gaseous products will assist the recovery of coal mining and more plants of this character could be profitably built.

Although no discoveries of outstanding importance have been made, metallurgical research, during the year under review, has added considerably to our knowledge of metals and alloys, much attention has been given to factors that influence quality with a view to better control of operations. Probably one of the main indications of progress in industry is the gradual appreciation of the value of research and its effect not only on the development of better materials, but in improving the technique involved in manufacture. The economic advantages which accrue are not the least important aspects of the application of the results of research to practice. Valuable work has been done at the Physical Research Laboratory, by the British Non-Ferrous Metals Research Association, the British Cast Iron Research Association, and by many other Associations and Institutions. In addition, the steady work of many private research laboratories is a noteworthy factor associated with industrial progress. The recent opening of the new research laboratories of the L.M.S. Railway Co., at Derby is a further indication of the importance with which research work is regarded, Unfortunately there is time-lag between a research development and its application in industry, while this is unavoidable the modern trend is towards a reduced time-lag.

Under normal conditions the future of British trade and industry could be viewed with confidence, but a few disturbing factors influence an optimistic prospect. The influence of a speedy, peaceful solution to the coal problem would be helpful, but further afield the forces of disruption are at work, despite the efforts of the League of Nations, which may have far-reaching effects on world recovery, and do much to minimise the progress made during this year. The only methods by which recovery can continue are associated with peace, and it is hoped that an honourable and just peace may be agreed upon in the Italian-Abyssinian conflict.

Foundry Developments

By a Special Correspondent

Progress in the foundry is proceeding steadily, and in addition to developments in melting appliances and the modern trend in refractory materials, the author directs attention to the cast crankshaft which has attracted considerable attention.

Developments in Cast Iron

THE technical developments in the foundry industry have proceeded and are proceeding with unabated vigour, although it is not easy in the short space of a year to point to spectacular achievements. Research work comes slowly to fruition and records of discovery frequently lack the spectacular suddenness and surprise element. Considerable activity has been shown in the mechanisation of foundries and in the installation of equipment for continuous production. It is commonly thought that only mass-production establishments, those concentrating on one line or at the most a few lines of goods, offer opportunities for mechanisation. This, however, is far from being the case, and the principles can be applied successfully to foundries having a wide variety of patterns, provided, of course, these are in sufficient demand to justify machine production. The removal of auxiliary duties from the moulder and particularly the elimination of lifting and carrying by hand, results in large increases in production per man.

Melting Practice

The development of new melting units continues. The now well-known rotary furnace, fired either by oil or by pulverised fuel, finds increasing application and the small electric-arc furnace of the rocking type is now becoming available. Little change has taken place with regard to the cupola, except the continued progress of the balanced-blast type, evolved by the British Cast Iron Research Association. Over one hundred of these furnaces are now in use or under construction, having a total hourly output of over 700 tons, and they have been installed and operated with entire success in Australia, India, United States, Denmark and Czechoslovakia, as well as in this country. Many foundries find justification for the change in the economy in fuel, which is of the order of 25%–40% in many cases, but the high temperature of the metal and its relative freedom from oxidation are important assets which more than justify its adoption. Research has shown the advantages that accrue to hot melting.

Sands and Refractories

So far as refractories are concerned, the special requirements of the rotary furnaces mentioned above have created new demands on the refractories industry, met at present almost entirely by plastic refractory materials of the siliceous type. Cupola refractories are undergoing close examination with a view to separating out the influence of many factors concerned on the life both of the brick lining and of the plastic refractory used for repairs. In moulding sands there has been a definite tendency towards the use of a fine clay addition and here again investigations are in progress with a view to determining the best conditions for such mixtures, with special reference to the amount to be added and the moisture required. This tendency is specially noted in mechanised plants where a much higher degree of technical control of raw materials is necessary, than in an ordinary foundry. In other foundries, of course, the use of natural sands is bound to continue to predominate.

Metallurgical Developments

Among metallurgical developments which have attracted considerable attention is that of the cast crankshaft. Although at one time it would have been considered inconceivable that cast iron could be used for automobile crankshafts and camshafts, the Ford Company has now standardised on a cast shaft and active development is proceeding in other quarters. The cast shaft is simpler to manufacture and cheaper to machine. It has been shown under test that cast iron wears as well as, if not better than steel. Perhaps the most important advantage, however, lies in what is now called the damping capacity of cast iron. It is well known that service stresses imposed on the crankshaft, differing slightly in frequency, may produce a condition of resonance in which the stresses build up to a point which causes failure. Cast iron, however, has a capacity for absorbing these stresses which consequently do not build up in this way. The Ford material formerly used was a forged and heat-treated steel crankshaft of about 0·3%–0·4% carbon of the usual type. Attempts to improve the life and reduce the cost of this material by means of die-casting were made and an annealed white iron was tried. Finally a 2% carbon material was cast in greensand, having various alloy additions. Ultimately a low carbon-manganese-silicon-copper-chromium alloy was evolved, given now as 1·35%–1·6% carbon, 0·6%–0·8% manganese, 0·85%–1·1% silicon, 1·5%–2% copper, 0·4%–0·5% chromium, with phosphorus below 0·1% and sulphur below 0·6%. Each mould carries four crankshafts and they are subsequently heat-treated in gas-fired furnaces. The tensile strength is about 48 tons per sq. in., the transverse strength about 75 tons per sq. in. The tensile bar gives about 2·5%–3% elongation Brake drums and other parts are now being made in the cast form, and the structure shows fine pearlite with a small amount of temper carbon. The latter indicates that the material is metallurgically a true cast iron, the alloy conditions lowering the carbon content to a figure which would make the composition a steel if there were no alloy additions present. The most complete information on this development to date is due to Mr. E. F. Cone, who says that the new cast shaft weighs about 10% less than the forged shaft, which was 83 lb. in the rough and 66 lb. after machining, while the cast shaft is 69 lb. and 60 lb. after machining. During the past two years over a million and a half cast shafts have been produced and assembled at Detroit.

It is also of interest to record that a new process of graphite refinement recently evolved by the British Cast Iron Research Association is to be applied with the co-operation of the British Iron and Steel Federation to ingot moulds. These moulds require graphite in order to confer resistance to thermal shock and hitherto this has always existed in the coarse condition, which renders the material prone to failure by growth or internal oxidation. The ingot mould design, composition and structure has thus to achieve a compromise between the tendency on the one hand to fail by cracking and on the other hand to fail by growth which leads to the crazing of the working face. Considerable progress has been made on alloy cast irons and their heat treatment.

Finishing Processes

The use of vitreous enamelled cast iron has spread with remarkable rapidity and a number of technical problems involved in these have been met, and in some measure solved. The attention given to welding in recent years was reflected in the symposium organised by the Iron and Steel Institute and a number of other technical societies.

Testing

In the testing field, attention may be drawn to three important papers recently given to the Institution of Mechanical Engineers by Mr. L. W. Schuster on the bend test, by Dr. H. Gough and Mr. Pollard, on the effect of combined stresses on iron and steels and by Mr. R. W. Bailey on creep. This remarkable group of papers will receive world-wide attention.

Progress in Corrosion- and Heat-resisting Steels

By Dr. W. H. HATFIELD, F.R.S.,
Director, Firth-Vickers Stainless Steel Co., Ltd.

Corrosion-resisting steels have now become widely known and are being used in ever-increasing quantities, but the variety of heat-resisting steels now available are just beginning to be appreciated. In this article the developments of both types of steels is described, and in view of their attractive properties numerous industries will find their application essential for many purposes.

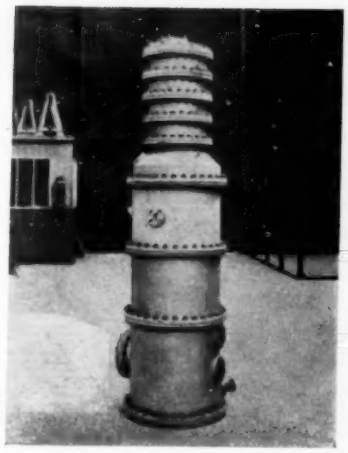


Fig. 1.—Concentration column in "Staybrite" steel.

FROM time to time during the past 10 years or so, much has been written and said regarding the general question of corrosion- and heat-resisting steels, but it may be useful to give a brief survey of the various types of these steels at present in regular use in this country, with some indication of their properties and uses.

Corrosion-Resisting Steels

It is well known that of all the possible different elements which may be added to steel, chromium is the most important and useful as regards inducing resistance to corrosion, and it will be seen that a high chromium content, apart from other alloying elements, is an essential ingredient in all such steels.

The year 1913 saw the production in this country of what may be looked upon as the first plain chromium-stainless steel, for, although, prior to this, several different investigators both here and abroad, had made steels with high chromium contents, it was not until 1913 that the real nature and significance of this class of steel, as regards corrosion-resistance, was appreciated. This first stainless steel contained about 0·3% of carbon and about 13·0% of chromium, and was successfully manufactured into table cutlery, and as a matter of fact, this same composition, with very little modification is being used to-day for the production of stainless cutlery, and for many other purposes where resistance to corrosion is required, coupled with appreciable hardness.

What are generally known as stainless irons, these really being mild, or low carbon stainless steels, are a natural outcome of this original stainless steel. Whereas the stainless steel with 0·3% carbon and 13% chromium can be hardened to a Brinell hardness of 450–550 (depending on the section), the lower carbon in the so-called stainless irons does not permit of their being hardened to the same degree, and, in fact, if the carbon is below about 0·1% and particularly if the chromium is a little on the high side, the steel is essentially non-hardening. The great advantage of stainless iron over stainless steel was of course, that it was much more ductile and malleable, and therefore more satisfactory for cold-working operations, particularly in sheet form, for example, for cold pressing, stamping, etc. Plain chromium stainless irons, like the original stainless steel, are still being made and used, although, for many purposes, they have latterly been superseded by the austenitic high chromium-nickel steels. Whereas, for general purposes, stainless irons contain about 13% chromium, with low carbon (sometimes less than 0·1% and sometimes up to 0·15%), higher chromium stainless irons, with chromium 16 to 18% are used for special conditions.

Stainless irons are generally put into service in the fully tempered or annealed condition, and have mechanical properties of the following order:—Yield point, 18–25 tons per sq. in.; maximum stress, 30–40 tons per sq. in; elongation, 30–40%.

Following the introduction of plain chromium stainless steels and stainless irons, there took place concurrently at the Brown-Firth Research Laboratories, Sheffield, and in the Research Department of Messrs. Krupp of Essen, Germany, a considerable amount of experimental work and research into the possibility of producing other types of stainless steel with superior corrosion-resisting and mechanical properties to the already known plain chrome-stainless steels. A considerable amount of fundamental research was carried out to determine the resistance to corrosion of pure metals such as iron, chromium and nickel, separately, and then to ascertain the optimum combinations of these metals to give the best corrosion resistance combined with suitable mechanical properties, for, it must be borne in mind of course, that excellent corrosion resistance is of little practical value, if the material has such poor mechanical and physical properties that it cannot be worked and manipulated in, at any rate, a similar manner to ordinary steels.

Taking carbon, iron, chromium, nickel, manganese and silicon (apart from several other alloying elements), one can imagine the tremendous number of possible variations of these elements, and in the Brown-Firth Research Laboratories something like 1,100 of these possible variations in analysis have been made and examined. The result of this work, spread over several years, was the evolution and introduction of what has become known as the austenitic 18/8 class of corrosion-resisting steels, typified by the well-known Staybrite steels made by Messrs. Firth-Vickers Stainless Steels, Ltd., Sheffield.

As the name implies, these steels contain essentially about 18% chromium and 8% nickel, and indeed, the first steels of this type actually contained 18% chromium and 8% nickel with about 0·10% carbon, with no other special elements.

In the first place, the resistance to corrosion of these austenitic 18/8 steels was found to be vastly superior to that of the plain chromium stainless steels and irons, and in the second place, the mechanical properties of the 18/8

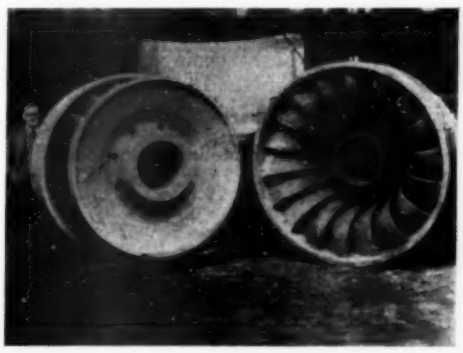


Fig. 2.—Large cast impellers in Firth - Vickers stainless steel.

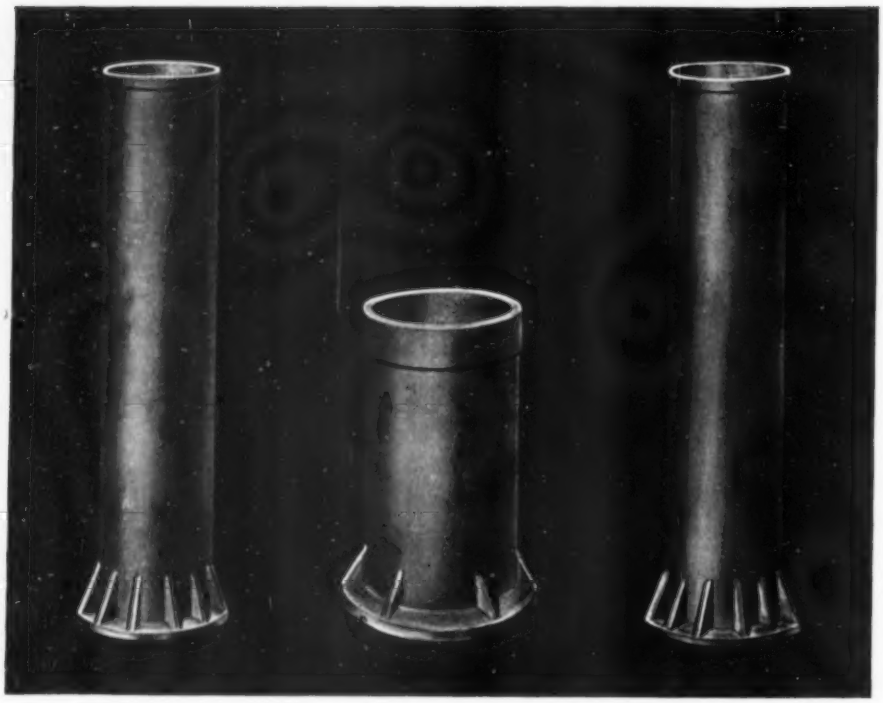


Fig. 3.—Pulverized fuel burner nozzles for rotary cement kilns in Firth-Vickers heat-resisting steel.

steels were of a quite different order from the plain chromium-stainless steels, showing greatly increased ductility and capacity for cold de-formation.

As indicated earlier in these remarks, a plain 12 to 14% chromium steel, with a medium carbon content, is capable of being hardened to a high degree of hardness, as typified by the use of this steel for stainless knives, whereas, on the other hand, the 18/8 class of steel, by virtue of the addition of 8% of nickel to the high chromium content, possesses no " change points " or " critical points " on heating and cooling, and therefore is not capable of being hardened by heat-treatment. In the soft condition—*i.e.*, heated to about 1,100° C. and cooled quickly, the 18/8 steel has a yield point of about 16 tons per sq. in., with a maximum stress of about 40 tons per sq. in. and an elongation of 40–60%, and it is the remarkable ductility of the steel, coupled with its superior corrosion resistance, which is so valuable in the working up of the material into the wide variety of plant and apparatus for which this class of steel is now being used.

Amongst several advantages which the austenitic chromium-nickel steels possess over the straight chromium stainless steels is that of weldability. Whilst the plain chromium steels can be welded, this operation is not generally recommended on such steels, since the welding of steels which tend to air-harden on cooling from high temperatures is always attended by difficulties such as cracking, etc. The austenitic chromium-nickel steels are particularly suitable for welding in that the welding itself presents no difficulty, and there is no risk of cracking resulting from air-hardening. Nevertheless, shortly after the introduction of the 18/8 steel, it was found that if the steel were welded and then submitted to certain corroding media, the steel in the immediate vicinity of the weld, where it had been heated during the welding operation to a temperature between about 500° and 900° C., was susceptible to a particular type of corrosion known as intercrystalline corrosion or " weld decay." To put it briefly, the mechanism of this type of corrosion is that on heating to 500-900° C, carbides in solid solution in the steel are deposited along the crystal grain boundaries, and on subjecting the steel to certain corroding media, corrosive attack takes place between the crystals, thus rendering the steel very brittle in these areas adjacent to the welds.

This was, of course, a serious disability, but it was found that if, after welding, the material was heat-treated by taking up to a temperature of 1,100° C. and cooled quickly (thus taking the deposited carbides back into solid solution) the material was free from the tendency to intercrystalline corrosion. It soon became evident, however, that heat-treatment after welding was either impracticable or not commercially possible for many jobs, so that investigation was then carried out into ways and means of obviating this disability.

The problem has been attacked from different angles. For example, it would appear logical to suppose that if the intercrystalline corrosion tendency was due to the presence of carbides deposited at grain boundaries, the trouble might be eliminated by reducing the carbon content of the steel, and as a matter of fact, this is one method adopted to obviate or reduce the trouble, so that one hears of 18/8 steels with a carbon content of 0·07% *max.* However, it has also been shown that the addition of a small amount of tungsten and titanium to the steel, renders the steel entirely immune from any susceptibility to intercrystalline corrosion or " weld decay," in which case it is not necessary to keep the carbon content down to very low limits, and for general plant construction, involving welding and other forms of heating during manipulation and manufacture, advantage is taken of these facts.

From time to time, the effect of additions of other alloying elements, to the 18/8 type of steel have been suggested and tried, and of these, molybdenum may perhaps be considered the most useful, and 18% chromium, 8% nickel steels containing up to 3% of molybdenum are on the market. The addition of the molybdenum to the 18/8 steel improves its resistance to hot, strong solutions of acetic acid, to dilute solutions of sulphuric acid, etc.

At this point, it is of interest to refer to the fact that, whereas the 18/8 chromium-nickel steel offers considerable advantage over stainless iron as regards greater ductility and malleability (apart from superior corrosion resistance) nevertheless, a few years ago, the Brown-Firth Research Laboratories, as a result of further research, introduced a steel (now known as Staybrite D.D.Q. steel), which is even better than the 18/8 type for purposes involving a very considerable amount of cold work for example, in the production of domestic hollow ware, spoons and forks, decorative purposes, etc. This steel contains 12 to 13% each of chromium and nickel, with low carbon, and in addition to being initially somewhat softer than the 18/8 steel (130–140 Brinell hardness, as against 160–180 Brinell hardness), this steel cold work hardens at a lower rate than the 18/8 steel, which of course, is an advantage in say, deep press work.

Approximately concurrent with the introduction of the austenitic chromium-nickel steels, there was introduced another stainless steel, which is now well known under B.S.I. Specification S. 80. This steel contains between 16 and 20% chromium, together with about 2·0% nickel, and low to medium carbon content. As regards corrosion resistance, as would be expected from the chrome and nickel contents, this steel lies somewhere between the plain chromium-stainless steels and the austenitic chromium-nickel steels. Moreover, it is amenable to hardening and

tempering treatments, and is usually put into service in the hardened and tempered condition, with a yield point of about 40 tons per sq. in., maximum stress 50–60 tons per sq. in. and an elongation of about 20%. This particular steel is suitable in cases where mechanical strength higher than that of the austenitic chromium-nickel steels is required, and where corrosion resistance is than that of the plain chromium stainless steels is required.

From what has been said above, therefore, regarding corrosion-resisting steels, it will be seen that during the past 20 years, there have been great strides in this field. Furthermore, it is no exaggeration to say that it is now possible to obtain corrosion-resisting steels in practically any form in which ordinary steels and even non-ferrous metals are obtainable, and also that present-day corrosion-resisting steels can be manipulated in practically any way in which ordinary steels and non-ferrous metals are manipulated.

Whilst it should be understood that the term " stainless " or " corrosion-resisting " steel is a relative term, and that no stainless steel will resist all acids and all other corroding media, nevertheless there is tremendous scope for corrosion-resisting steels in a wide variety of industries. Again, whilst the price of corrosion-resisting steels is such that it is unlikely ever to entirely replace ordinary steels, there are numerous directions in which these special steels are being increasingly applied, and are more than justifying their extra cost.

Heat-Resisting Steels

Whilst the use of special steels for heat-resisting purposes has come into prominence essentially during the past 10 years or so, plain chromium steels, containing about 12% chromium and 0·4% carbon were being used 20 years ago for exhaust valves for internal-combustion engines. In these days, such a steel is still being used for certain purposes for resistance to oxidation up to 700–750° C.

Speaking generally, the term " heat-resistance " really involves a combination of two different factors or qualities – *viz.* (1) resistance to corrosion or oxidation at elevated temperatures and (2) maintenance of mechanical strength at elevated temperatures.

As regards retention of mechanical strength at the higher temperatures– *i.e.*, above 500° C. or so, the austenitic chromium-nickel steels are distinctly superior to the plain chromium or silicon-chrome types. Thus, heat-resisting steels can be broadly divided into two classes– *viz.*, martensitic or ferritic (having good scale resistance), and austenitic (having, in addition to good scale resistance good mechanical properties at high temperatures).

It will be appreciated that, so far as cost is concerned, the austenitic steels are more expensive than the martensitic steels because, not only do the austenitic steels contain more expensive alloying elements, but also, such steels, from the very fact that they possess greater mechanical resistance at elevated temperatures, offer more difficulty in production, such as for example, forging and rolling.

For both main types of heat-resisting steels, there are naturally a number of different compositions with varying degrees of resistance to oxidation and with varying mechanical properties. Also, in either of the two groups, one steel may be suitable for castings, but may not have suitable mechanical properties for the production of, say, sheets and strip, or may not be suitable for severe cold de-formation, so that, quite apart from the questions of oxidation resistance, and mechanical properties at elevated temperatures, one has to consider the form in which the steel is required as well as the functions it has to perform.

It may be well, therefore, to indicate some of the heat-resisting steels in use, giving some indication of their properties.

So far as plain chromium heat-resisting steels are concerned, there are three main types—*viz.*, 10–14% chromium, 16–20% chromium and 25–30% chromium. As regards oxidation resistance these are very good up to 700–750° C., 900° C. and 1,050–1,100° C. respectively, but these steels

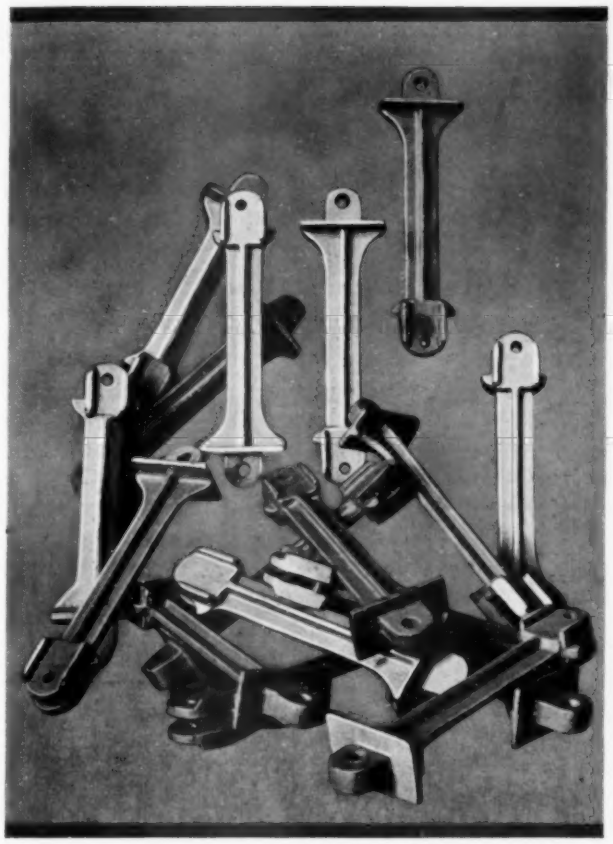


Fig. 4.—A group of furnace parts in Firth-Vickers heat-resisting steel.

are very little better than ordinary steels so far as mechanical properties at high temperatures are concerned.

Advantage has been taken of the beneficial effect of silicon, in increasing resistance to oxidisation, and by the addition of 3 to 3½% silicon to a steel containing about 8% chromium, the well knowr type of heat resisting steels known as silicon chrome steels, has come into wide use. This class of steel is very resistant to oxidation up to about 900° C., although it possesses little mechanical strength at high temperatures. Nevertheless, this steel is used with success, in very considerable quantities, for exhaust valves for internal-combustion engines.

The austenitic high chromium high nickel steels (with or without small additions of other special elements) have come very much to the fore during the last few years on account of the fact that, in addition to their enhanced resistance to oxidation, these steels undoubtedly possess superior mechanical properties at high temperatures, this latter feature being of considerable importance for a number of applications where the steel is required to withstand stress at an elevated temperature. Also, generally speaking, the austenitic chrome nickel heat-resisting steels, having superior ductility at ordinary temperatures to the plain chromium steels, are more adaptable for general manipulation, such as hot and cold pressing, forming, tube-drawing, etc. Further, the austenitic heat-resisting steels are much more suitable and reliable for welding.

It will be appreciated from what has been said earlier regarding the 18/8 chrome-nickel corrosion-resisting steel, that such a steel would not be suitable for use at elevated temperatures, owing to the liability for intercrystalline corrosion to occur after exposure to temperatures of the order of 500–900° C , but advantage is taken of the addition of a small amount of tungsten and titanium to the 18/8 steel to produce a steel which is not only an excellent corrosion-resisting steel, suitable for welding, but which is also a useful heat-resisting steel for use up to about 800° C. At a temperature of 800° C., the tensile strength of ordinary

mild steel, as determined by an ordinary tensile test at the temperature, is about 4 tons per sq. in., whereas the 18/8 steel with tungsten and titanium additions, at 800° C. has a tensile strength of about 13 tons per sq. in. It is appreciated that the results of an ordinary tensile test at elevated temperatures do not give a safe and reliable criterion as to the safe maximum working stress allowable at elevated temperatures, but it is not proposed in this article, to go into the question of "Time-Yield" and "Limiting Creep Stresses," and their interpretation. Suffice it to say that the ultimate tensile strength obtained by carrying out an ordinary tensile test at high temperatures may serve as a rough guide or indication as to the order of comparison of the strength of the different steels.

An excellent steel for use up to 1,050° C. or possibly even to 1,100° C., is one containing approximately 20–25% chromium, and 20–25% nickel, with carbon on the low side. This steel retains very good mechanical properties at the high temperatures, and at the same time possesses sufficient ductility to enable it to be produced in the form of solid drawn tubes, this not being practicable, or at any rate commercial, with the majority of the heat-resisting steels.

A variant of this type of steel is one containing about 26% chromium and 10% nickel. This is naturally somewhat cheaper than the 20–25% chromium-nickel, and is usually made in the form of castings. Where even higher mechanical properties at high temperatures are required, the addition of 2–4% of tungsten to a high-chromium high-nickel steel, is a decided advantage, and there are on the market, several steels with varying chromium and nickel contents, containing 2–4% tungsten. For example, a steel containing about 13% each of chromium and nickel and 2–3% tungsten. is used for exhaust valves under onerous conditions, where the higher mechanical strength of this steel, as compared with plain chromium or silicon-chrome types of steel, is advantageous.

Again for stressed parts at high temperatures, steels are available with chromium up to 25% and nickel 8–12% (and in some cases, up to 30%) with 3–4% tungsten, whilst finally, high nickel-chromium alloys (one can scarcely call them steels), of the order of 60% nickel and 20% chromium, are used for certain purposes up to about 1,150 ° C.

Conclusion

In conclusion, it may be stated that, whereas corrosion-resisting steels have now become widely known and are being used in ever-increasing quantities, industry, as a whole, is only just beginning to appreciate the variety of heat-resisting steels which are available, but there is no doubt that, in spite of their relatively high initial cost, advantage will be taken of their attractive properties, and more extended use made of them, in the same way that corrosion-resisting steels have become a practical necessity to numerous industries in this country.

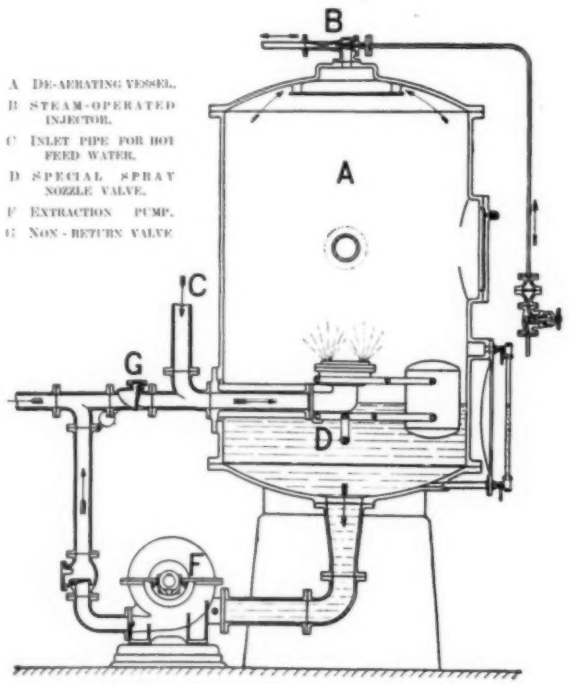
Removal of Oxygen from Feed Water

THE latest practice in the operation of water tube boilers, which are being more and more used in the iron and steel and allied industries, is to de-aerate the boiler feed water to below, say, 0·05 c.c. of oxygen per litre (1,000 c.c.) so as to prevent corrosion. The most convenient and efficient method of de-aerating is treatment under vacuum, the solubility of oxygen in water being, of course, dependent upon the temperature and the pressure. In this connection considerable interest attaches to recent designs of de-aeration plant made by Hick Hargreaves and Co., Ltd., of Bolton, which gives an extremely high efficiency, resulting in water having not over 0·05 c.c. dissolved oxygen per litre, whilst at the same time being simple in design and operating with an open hot-well or supply tank.

Essentially the principle consists in spraying the warm feed water, using a special design of spray nozzle valve, into a closed cylinder, which is maintained at a high vacuum by a steam ejector. This eliminates all complicated mechanically operated vacuum pumps, and the good results largely depend upon the extremely finely divided particles of water given by the spray. Under these conditions the oxygen almost instantaneously passes out of solution in the water to such a degree that often much less than 0·05 c.c. per litre remains. Thus in some cases, with great care taken in sampling to prevent air contact, the amount of oxygen is less than 0·01 c.c., and cannot be determined by the standard Winkler test, using manganous hydroxide and potassium iodide, with the liberated iodine, equivalent to the oxygen, situated by standard sodium thiosulphate solution, with starch as the indicator.

The de-aerator consists of a vertical closed cylinder, forming the de-aerating vessel, having the steam ejector at the top. Warm feed water at, say, 130° F., enters by an inlet pipe at the side of the cylinder and passes direct to the special spray nozzle valve, situated in the centre lower portion of the de-aerating vessel, the inlet flow being controlled by a bucket float which maintains a constant water level in the de-aerating vessel.

All the feed water is discharged continuously with great force in the form of the spray, losing its oxygen mainly



Vertical section of atomising spray de-aerator.

because of the extreme sub-division in the vacuum, as already indicated, and falling to the bottom. From the de-aerator vessel the water is taken by a motor-driven rotary extraction pump and discharged to the boiler-feed circuit, which has a non-return valve between the de-aerator inlet and the extraction pump discharge. Under these conditions if the extraction pump is stopped water can pass automatically direct to the boiler-feed pump. Also the steam ejector discharges the small amount of steam used along with the extracted air to the cold inlet water, giving a very high over-all thermal efficiency.

Correspondence

Electric-Resistance Alloys

The Editor, METALLURGIA.

Sir,—Mr. Russell's straightforward discussion, in the November issue of METALLURGIA, of my previously published paper on "Electrical Resistance Alloys" has brought into the open a controversy that, in the past, has been dignified more by subtlety than by public expression of opinion.

There is certainly some justice in Mr. Russell's comment. Undeniably, the Kanthal alloys are superior in oxidation resistance to nickel-chromium at any temperature; this, coupled with a highermelting point, makes possible the use of a Kanthal-type material at temperatures 200° C. higher than the operating maximum for nickel-chromium. It should be stressed, however, that iron-chromium-aluminium alloys, with or without cobalt, are used above 1,100° C. only because of their superior oxidation resistance, and in spite of inferior mechanical properties that prevent them from competing successfully with nickel-chromium below this temperature. This is not a generalisation but a statement of demonstrable fact, based on careful examination of both nickel and iron-base resistors, and on standard life tests performed *strictly* in accordance with the American Society for Testing Materials specifications. That the results of such tests performed in America are in disagreement with Mr. Russell's claims, and with data collected and published by the iron-chromium-aluminium-cobalt manufacturers, is due, I believe, to an important difference in the method of test and to a difference in the quality of nickel-chromium alloy used for comparison.

The A.S.T.M. Accelerated Life Test for Metallic Materials for Electrical Heating was developed by a committee representing the entire industry in America, manufacturers, users, and those interested in a general way. Mr. Driver and Mr. Hahn, of the Wilbur B. Driver Co., contributed much of their time and energy to the development of the test. We are in a position to know, therefore, that it represents actual service conditions as closely as any accelerated test can be made to do. A study of these service conditions indicated that in most applications resistance to hot deformation was as important a factor as resistance to oxidation, hence the test was made to include the application of a slight external tension to the specimen, simultaneous with intermittent passage of current through it. In addition, the voltage supplied to the specimen during test is maintained at a constant value (after a preliminary 24-hour temperature adjustment period), and record is made of the increase in electrical resistance of the specimen during the test. *The useful life of a specimen under these conditions is considered to have ended when its resistance has increased to* 110% *of the original value.* A 10% increase in resistance is accompanied by a 9% decrease in wattage, and a corresponding drop in temperature of the specimen being tested. The *total life* of a wire, therefore, is important only when the elapsed time to burnout is only slightly longer than the *useful life*, or when the specimen has not increased its resistance 10% to the time of burnout.

These are important considerations. Obviously, a resistance wire that has a relatively short "useful life," and therefore cannot maintain its temperature throughout its total life, is unsatisfactory for most applications (especially domestic) where constant voltage conditions obtain. When iron-chromium-aluminium-cobalt alloys are tested under constant voltage conditions with slight tension (about 35 lb. per sq. in.), their "useful life" is shorter than that of the best grades of American nickel-chromium wire. The accompanying hitherto unpublished data are taken from tests performed by H. J. Hahn and J. F. Polak, of this Company, on samples of Kanthal alloys and Trophet A (80 Ni—20 Cr):—

In each case in which the test was stopped before burnout it is quite probable that the specimen would have lasted several hundred hours longer; but because the 10% resistance increase point had been passed long before, and the specimen was no longer burning reasonably close to the original temperature, additional data would have been meaningless. Furthermore, in the tests that were stopped before burnout, the specimen had grown in length to such an extent that the wire had bellied out and was touching other parts of the apparatus at several points. This phenomenon of "growth" we have observed to be characteristic of the iron-chromium-aluminium-cobalt alloys when tested by the A.S.T.M. method.

Alloy.	Size (In.).	Original Temperature C.	Useful Life (to 10% Resistance Increase).	Total Life (to Burnout).	Resistance Increase at Burnout or at End of Test.
					%
Kanthal A_1	0·020	1,200	5·5	stopped 120	50
Kanthal A_1	0·020	1,250	2·5	36	37
Kanthal A_1	0·020	1,325	immediate	burnout	—
Tophet A ..	0·020	1,200	54	54	8
Tophet A ..	0·020	1,250	0·12	0·12	—
Kanthal A_1 .	0·025	1,120	44	stopped 360	23
Kanthal A..	0·025	1,120	35	stopped 360	26
Kanthal D..	0·025	1,120	31	stopped 360	29
Tophet A ..	0·025	1,120	78	78	5·5
Tophet A ..	0·025	1,120	79	79	6·6
Kanthal A_1	0·025	1,065	96	stopped 360	16
Kanthal A..	0·025	1,065	129	stopped 360	15
Kanthal D..	0·025	1,065	53	stopped 360	17
Tophet A ..	0·025	1,065	228	228	7·5
Tophet A ..	0·025	1,065	250	250	10
Kanthal A_1	0·0285	1,065	168	231	13·5
Kanthal A..	0·0285	1,065	216	stopped 334	—
Kanthal D..	0·0285	1,065	310	stopped 334	—
British	0·0285	1,065	120	147	—
80/20 Alloy	0·0285	1,065	100	156	—
Tophet A ..	0·0285	1,065	296	296	8·5
Tophet A ..	0·0285	1,065	312	312	7·6

Examination of these data will show that the statements in my original paper were not at all misleading. Under no set of similar conditions did any one of the Kanthal alloys surpass the Tophet A in "useful life" below 1,200° C. On the contrary the Tophet A in several cases lasted *twice* as long—to 10% increase—in resistance as did the best Kanthal alloy at the same size and temperature. The Tophet A used, furthermore, was taken from a stock coil, known as our "Lift Test Standard," melted and drawn several months ago. Current production lots of Tophet A show a much longer life on test than does the standard sample used for the foregoing comparisons, because of the constant improvement in the quality of the alloy.

The above figures do not confirm those obtained by the iron-chromium-aluminium-cobalt manufacturers. Because an analysis of their figures might clarify the situation let us examine a recent publication of data on Kanthal—an article entitled "Alloys Good at Temperatures above 2,100° F.", by Gunnar Nordstroem, Chief Engineer of Aktiebolaget Kanthal, in *Metal Progress* for October, 1935. Mr. Nordstroem includes in this article a chart from which may be taken the accompanying life-test data:

No resistance figures are given, so that it is not unreasonable to assume that the time values represent "life to burnout" rather than the more significant life to 10%

increase in resistance. It should also be noted that Mr. Nordstroem, in describing his tests, writes: Apparatus and methods used for this work are identical with that recommended by the American Society for Testing Materials, *except that at high temperatures the wires are subjected to no other load except their own weight.*" (The italics are mine.) Interesting though such data may be as indicating the length of time that the alloy will burn before ultimate failure, they should not be considered too seriously when resistance changes are not included among them, and when the testing method includes the very important exception from the standard procedure just noted.

Alloy.	Temperature.	Life.
	°C.	
Kanthal A_1	1,200	275
Kanthal A	1,200	160
Kanthal D	1,200	120
80 Ni—20 Cr	1,200	60
Kanthal D	1,100	260
80 Ni—20 Cr	1,100	160

In METALLURGIA for October, 1932, Mr. Russell published an article on "Kanthal": it is interesting to note that the life given by Mr. Russell in 1932 for Kanthal A_1 and Kanthal A differs but slightly from the figures submitted by Mr. Nordstroem. In the three-year period Kanthal D has shown appreciable improvement, but not at all comparable to the 200% (or more) improvement effected in the quality of nickel-chromium alloys in the same time.

As mentioned previously, it is possible that the nickel-chromium used by the iron-chromium-aluminium-cobalt manufacturers for their comparisons in the past has been of a grade inferior to the better grades of American nickel-chromium. Included in the tests performed in the laboratories of the Wilbur B. Driver Co., were some of samples of 80Ni–20Cr submitted with the Kanthal by an English firm. It will be seen that the life of the British product is somewhat less than the Kanthal alloys and only 36% as great as the Tophet "A" tested under similar conditions.

Too much stress cannot be laid on mechanical properties. Especially for household applications, the quality of service rendered by a resistance wire is far more important than the length of service, for with even a poor life wire, the heating element will invariably outlast style changes and defection of other parts of the appliance. The wire that retains its strength better, the wire therefore that sags less in service, will be far more satisfactory. Mr. Russell is correct in stating that unsupported nickel-chromium wire will sag, but he forgets that at 1,100° C. it will sag only 25% as much as an iron-chromium-aluminum-cobalt alloy. The tensile strength of nickel-chromium at 1,100° C. is 6,500 lbs. per sq. in.: according to Mr. Nordstroem the tensile strength of Kanthal is 1,520 lbs. per sq. in. at the same temperature. While special designs may provide adequate support for the Kanthal elements, such adjustments are not always convenient: the less temperamental alloy would certainly seem to be the more desirable from a general engineering standpoint.

I should like to add that the comparative tests performed by Mr. Hahn and Mr. Polak were part of an investigation of iron-chromium-aluminium-cobalt alloys, not as competitive materials, but as a possible addition to the group of products sold by this company. Only after repeated tests of the Kanthal materials had failed to substantiate the claims made for them by the manufacturers was the original enthusiasm for their potentialities dimmed in this organization.

In summation, therefore, our experience and that of many American users of resistance wire that have also investigated the iron-chromium-aluminium-cobalt alloys indicate that (a) Kanthal alloys will resist oxidation at higher temperatures than nickel-chromium; (b) the useful life of Kanthal alloys at temperatures lower than 1,150° C. is less than that of the better quality nickel-chromium alloys; (c) the Kanthal alloys are still subject to several mechanical difficulties, chiefly loss of strength at high temperatures, and brittleness, and special precautions must be taken in their fabrication and in the design of equipment in which they are to be used. This last admission is made by Mr. Nordstroem in his article in "Metal Progress" as well as by the manufacturers and their agents in their catalogue. We maintain, finally, that the Kanthal alloys are most useful above 1,150° C., where concessions should be made because of their superior oxidation resistance, but that below this temperature, their performance is definitely inferior to that of nickel-chromium.

December 2, 1935. FRED P. PETERS.
Newark, N. J.

Copper Developments

(*Continued from page* 60.)

The Ford Motor Company[19] are producing camshafts from an iron of composition given under the last column of Table I. and in this instance the copper has resulted in graphitisation to such an extent that the castings are machinable.

TABLE I.

COPPER CAST IRONS AND STEELS USED BY FORD MOTOR COMPANY

	Crankshafts. %	Cylinder Castings. %	Camshafts. %
Carbon	1·35 to 1·60	3·15 to 3·35	3·30 to 3·65
Silicon	0·85 to 1·10	1·80 to 2·10	0·45 to 0·55
Manganese	0·60 to 0·80	0·60 to 0·80	0·15 to 0·35
Copper	1·50 to 2·00	0·50 to 0·75	2·50 to 3·00
Chromium	0·40 to 0·50	—	0·00 to 0·25
Phosphorus	0·10 max.	0·25 to 0·32	0·05 max.
Sulphur	0·06 max.	0·10 max.	0·05 max.

Copper Moulds and Stools for Casting Steel.

Apart from its increased importance as an alloying element in irons and steels, copper has also created interest as a material for moulds and mould-bottom plates (or "stools") for casting steel ingots. Fairly heavy replacement costs are encountered with the cast-iron stools and moulds at present used, and in view of its much greater resistance to surface deterioration due to superior thermal conductivity, copper has been experimentally tried in U.S.A. and Great Britain, more particularly for stools.

According to results published by Williams and Kinnear[20] there are records of stool life ranging up to 1,500 casts with copper stools, as against an average of less than 100 casts from cast-iron stools. At the same time the life of the cast-iron moulds used in conjunction with these stools was found to be superior, due to the greater amount of heat conducted away by the copper stool and the consequent lower temperature of the mould itself. Due to the very high scrap value of copper it appears that for casting low-carbon steels the use of copper stools will prove to have economic advantages, but experience is being acquired in the casting of high carbon and other steels[21].

The casting of steel into copper water-cooled moulds is also being undertaken on an experimental scale. This development in casting practice is a natural sequence to that of the non-ferrous industry, in which notable improvements have resulted from the adoption of water-cooled copper moulds of the Junker type for the casting of strip ingots and of the more massive solid type for the casting of billets.

Lack of space prevents a description of all the other industrial developments connected with copper and with materials containing copper, but enough has probably been said to show that these uses are being expanded in many directions. This fact, coupled with the prospect that the price of the metal will be maintained at an economic level, makes the future outlook for copper consumption very favourable.

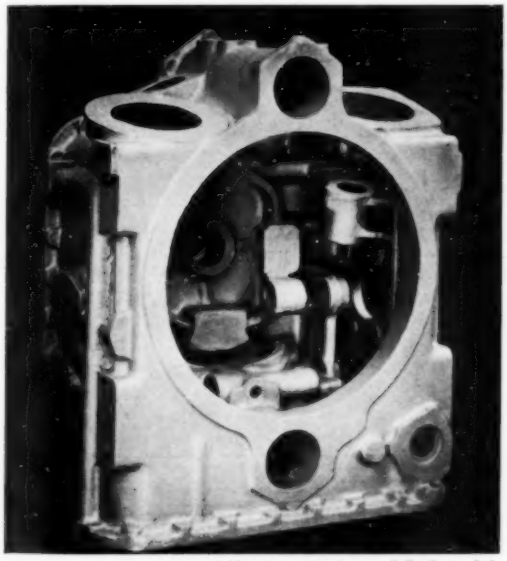
19 *Iron Age*, 1935, August 15, p. 22.
20 C. E. Williams and H. B. Kinnear, *Metals and Alloys*, 1935, 6, 169 and 213.
21 *Amer. Inst. Min. Met. Eng.*, Open Hearth Conference Minutes, April, 1935.

Recent Developments in the Manufacture and Applications of Magnesium and Magnesium Alloys

By W. C. Devereux, A.F.R.Ac.S.

The need for light alloys with good physical and mechanical properties has focussed attention on magnesium and magnesium alloys. Much progress has been made in applying these light alloys, and in this article the developments are briefly reviewed

THE intensive search for alloys combining good mechanical and physical properties with low specific gravity has added considerable impetus to the activities in magnesium and magnesium-alloy practice. The extraction of the metal from its ores, the available alloys, their casting, fabrication and protection against corrosion have been the subject of extensive study, resulting in the passage of magnesium alloys from the field of unstressed and lightly stressed parts to that of medium stressed components. The transition to the sphere of more highly stressed parts is the next step in this sequence, and present indications are that the very near future will see greater advances than have ever been experienced in this industry.



By courtesy of Magnesium Castings and Products, Ltd.

Fig. 1.—Timing-gear case cover in 8% aluminium-magnesium alloy.

Improvements in the electrolytic extraction processes have made available commercial grades of magnesium of 99·9% purity. Despite this achievement new methods receive due consideration and magnesium obtained by a direct reduction and distillation process has recently become available at a price comparable with and a purity equal to that produced by the older established processes. Detailed information regarding this method, now operating in England and in Austria, has not been published, but it is believed that one at least is based on the reduction of magnesium oxide by means of a carbonaceous material in an arc furnace in an atmosphere of hydrogen, this operation being followed by distillation, also in an inert atmosphere. The entire absence of reactive atmospheres and the consequent elimination of the necessity for fluxing the metal makes this process particularly suited to the production of a material of the highest quality.

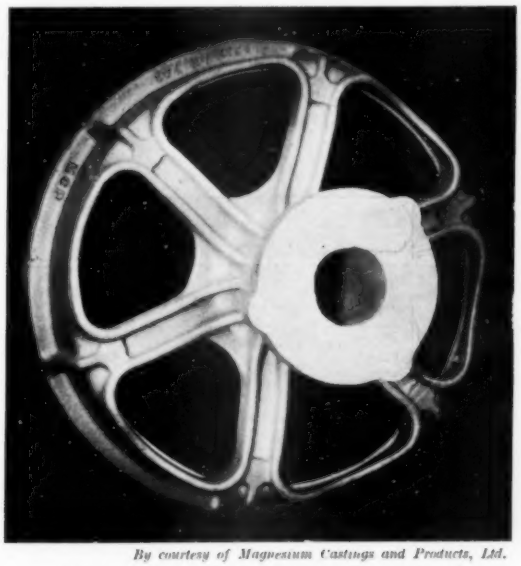
The casting of magnesium and its alloys is governed by two main factors :—

(1) the high reactivity of the molten metal when exposed to moisture or air, and

(2) the low density of the metal and its alloys.

The former consideration necessitates the use of inhibitors in the moulding material, when the moulds are used in the green state, and the expulsion of the air from the mould prior to pouring. As inhibitors sulphur, boric acid and ammonium bifluoride find most extended application, thereby eliminating any possibility of reaction between the metal and moisture. It should be noted that the use of these inhibitors is covered by patents.

Forging and stamping operations, impracticable in the



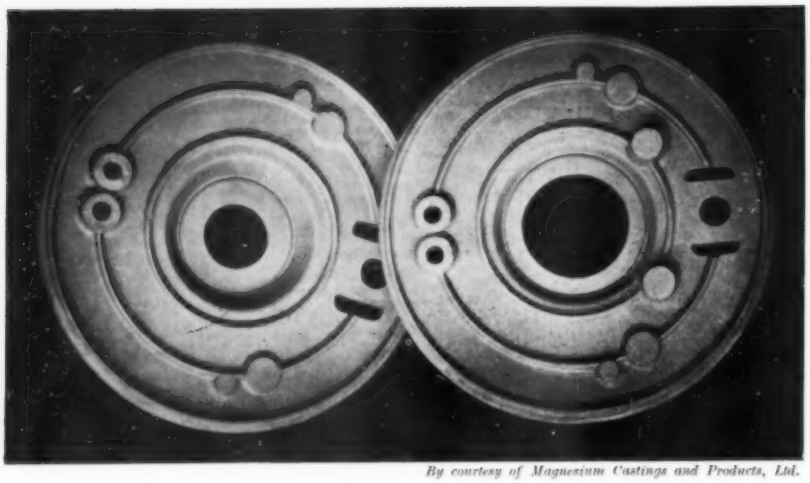
By courtesy of Magnesium Castings and Products, Ltd.

Fig. 2.—Hub and rim portion of an aircraft landing wheel.

cold, are entirely satisfactory if the metal and tools be heated. Below 225° C. deformation has to be restricted to exceedingly narrow limits if complete shattering is to be avoided, but above that temperature a far greater number of slip processes are possible and working operations are greatly facilitated. In practice, temperatures from 380°–420° C. are found most suitable.

If an ingot be worked in one direction only, it is found that the mechanical properties of the resulting article show a wide variation at different angles to the direction of deformation. Uniformity of properties can only result by alternating reduction and elongation operations in such a manner that the tendency to produce a fibrous structure is obviated.

Extrusion of magnesium and its alloys, which can be effected with comparative ease, opens up a large field for use of this form of material. Bars, tubes and profiles can



By courtesy of Magnesium Castings and Products, Ltd.

Fig. 3.—Brake-drum backing plates in sand-cast magnesium alloy.

be freely manufactured with physical properties such that moderately stressed components can be fabricated in this manner, and there is no doubt that in the near future physical properties comparable with the high tensile aluminium alloys will be attained.

Table I. gives the chemical composition of the alloys in general use, with the appropriate Air Ministry Specification. The mechanical properties to be expected from sand cast test bars in the "as cast" condition and from wrought material in the "as worked" condition are shown in

Magnesium base aluminium and aluminium-zinc alloys in cast form, with an aluminium content between 5 and 12%, may be heat treated with material benefit to their mechanical properties. The solution treatment, preferably conducted in a salt bath, conducted at a temperature of 425° C. for the aluminium bearing alloys and at 380° C. for the aluminium-zinc bearing alloys improves the strength and elongation properties. When followed by treatment at 160°–175° C. in an electric or gas-fired muffle, enhanced proof stress and hardness values result, at the expense of elongation.

Table III. illustrates the influence of heat treatment upon the mechanical properties of typical heat-treatable magnesium base alloys.

Protective treatments applicable to magnesium alloys have been developed which form a suitable basis for subsequent finishes which provide satisfactory protection against the corrosive conditions prevailing in marine atmospheres. Of these, the most satisfactory are the alkali chromate treatments developed at the Royal Aircraft Establishment, Farnborough, one modification of which can be applied to finished machined surfaces without affecting the final dimensions. The combination of such a surface treatment with cellulose or non-cellulose enamels has led to the extended use of magnesium alloys in highly corrosive atmospheres. Alternate treatments providing adequate protection in normal atmospheres are the acid chromate pickle (E.P. 287450) and the selenium treatment (E.P. 378916).

The advantages offered by the application of magnesium alloys have been freely recognised by the aircraft industry and rapid progress has been made in this sphere. In an industry where powerweight ratios have always been of the greatest importance this attitude was to be expected, and with the spread of similar ideas to the automobile and other industries the demand for lighter high-strength alloys has reflected on the magnesium situation.

TABLE I.—CHEMICAL COMPOSITION.

D.T.D. Specification.	Form.	Aluminium Maximum.	Zinc Maximum.	Manganese Maximum.	Magnesium Approximate.	Impurities Maximum.
59 A	Sand and gravity die castings	8·5	3·5	0·5	87	1·7
88 B	Forgings, stampings and pressings	11·0	1·5	1·0	86	1·5
259	Extrusions					
118	Sheet					
140 A	Sand and gravity die castings	0·2	0·2	2·5	96	0·5
142	Extrusions					
136 A	Sand and gravity die castings	9·0–11·0	3·5	0·5	85	1·5
—	Sheet (hard rolled)	9·0	1·5	1·0	88	0·7

TABLE II.—MECHANICAL PROPERTIES.

D.T.D. Specification.	Form of Test Bar.	0·1% Proof Stress, Tons/Sq. In.	Maximum Stress, Tons/Sq. In.	Elongation % on 2 in.	Maximum Compression Strength, Tons/Sq. In.	Modulus of Elasticity, Lb./Sq. In.	Brinell Hardness.	Fatigue Range, Tons/Sq. In.
59 A	Sand cast	4·0– 5·0	9·0–11·5	2– 8	23	$6·5 \times 10^6$	45–50	3·5
136 A	Do.	4·5– 5·5	8·0–11·0	2– 4	22–24	$6·5 \times 10^6$	50–60	3·5
88 B	Forged	10·0–14·0	18·0–22·0	10–14	22–26	$6·5 \times 10^6$	50–60	7·5
118	Sheet	6·0– 8·0	12·0–15·0	7–10	18–20	$6·0 \times 10^6$	40	5·0
259	Extruded	12·0–15·0	18·0–20·0	15–20	22–25	$6·0 \times 10^6$	50–60	4·0
—	Sheet (hard rolled)	7·0– 9·0	16·0–18·0	5–10	—	—	65–75	—

TABLE III.—MECHANICAL PROPERTIES OF HEAT-TREATED SAND-CAST ALLOYS.

Alloy.		Treatment.	0·1% Proof Stress, Tons/Sq. In.	Maximum Stress, Tons/Sq. In.	Elongation % on 2 ins.	Brinell Hardness.
Aluminium.	Zinc.					
8	—	Solution treated	4·0–5·0	13·5–15·5	10–15	45–50
10	—	Solution treated	5·0–6·5	14·0–16·0	5–10	50–55
		Solution treated and aged	7·0–8·5	15·0–17·5	1– 4	85–100
6	3	Solution treated	5·0–6·0	16·0–17·5	10–15	50–55
		Solution treated and aged	7·5–9·5	17·5–19·5	3– 8	65–75

Modern aero-engine units incorporate such cast parts as crankcases, gear and blower casings, rear covers and pressure-pump bodies. Figure 1 illustrates a timing gear case cover, sand cast in 8% Aluminium-magnesium alloy. This illustration of an intricate casting, indicates the possibilities of magnesium alloys in meeting the more exacting demands of aircraft castings.

A further application is shown in Figure 2. This casting of a hub and rim portion of an aircraft landing wheel, indicates the increased rigidity and weight-saving possibilities of such unit structures as opposed to the usual composite construction.

The application of magnesium alloys in the automobile industry has been assisted by the readiness with which their use has been adopted by the public utility and transport companies. The necessity for carrying the maximum pay load on vehicles such as omnibuses and lorries has resulted in the weight-saving use of magnesium alloys for such parts as crankcases, sumps, gear cases, flywheel covers, brake shoes, drums and plates. Figure 3 shows an example of a brake-drum backing plate in sand-cast magnesium alloy.

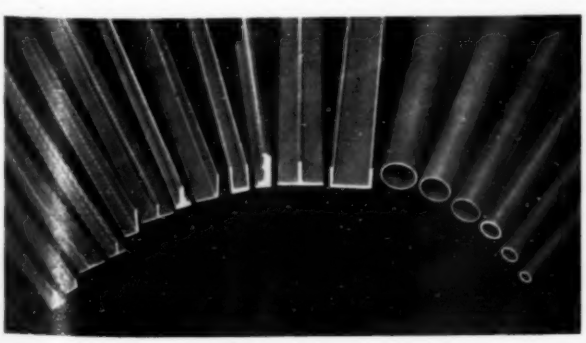
Forged and drop-stamped magnesium alloys have found a ready use in the construction of the modern aero engine for parts subject to moderate stress. Figure 4 shows a group of small stampings and pressings together with the three operations performed in the production of a larger type of forging. The ring is trunnioned out from a bored-cast billet and machined to final dimensions. The nature of the work performed in such a forging operation is indicative of some of the possibilities in forgings from these alloys.

Undoubtedly the most interesting application in this direction is the wrought airscrew. Considerable experience has been gained in this field and the degree of reliability attained suggests that a slight improvement in the mechanical properties of the finished blade would result in increased activity in this sphere. With the advent of the variable pitch propellor the possible saving in weight on such an assembly, which necessitates all metal construction, indicates an extended application in this direction. Figure 5 shows an extruded blade, and Figure 6 typical examples of tube and section.

Metal-skin construction, a feature of much activity at the moment with the probability of still greater activity in the near future, affords an outstanding example of the use of magnesium alloy sheet by aircraft constructors.

Fig. 6.—Typical examples of tube and sections.

By courtesy of Reynolds Tube Co., Ltd.



By courtesy of High Duty Alloys, Ltd.

Fig. 4.—Group of small stampings and pressings, and showing three operations in the production of a larger forging.

By courtesy of High Duty Alloys, Ltd.

Fig. 5.—An extruded propeller blade.

Owing to their superior mechanical properties combined with lower density these alloys tend to replace aluminium sheet in this connection.

The Use of Synthetic Moulding Materials in Magnesium Foundry Practice

By R. JONES, M.Sc.

The factors to be considered in the selection and preparation of a moulding material for the casting of magnesium and magnesium rich alloys are governed by the highly reactive character and low density of the molten metal and its alloys. The facility with which reaction occurs with sand and with the steam generated in green moulds, when the molten metal impinges on the mould face, necessitates the addition of inhibitors, a wide variety of which are now recognised as being of practical value. The low density of the metal and its alloys make it essential that the selected moulding material should be readily permeable by the gases generated in order that trapped gases may be avoided.

The close control necessary for the governing of such factors renders synthetic moulding materials particularly suited to this class of work. These are readily available in the form of dry-silica sands in a wide variety of graded-grain sizes which, by the addition of a suitable bonding agent may be rendered amenable to moulding. It is thus possible to work with the lowest concentration of water necessary for bonding, the dangers resulting from excess moisture being thereby reduced to a minimum and to attain the required degree of permeability to the gases evolved during casting.

It has been found that 5% by weight of pure-clay binder to 95% by weight of sand with addition of 4–6% of water, together with the necessary inhibitor, provides a moulding material particularly suited to the casting of magnesium and its alloys. Cores can be made from the same moulding material, with the addition of the necessary core oils, and by these means foundry practice is materially simplified.

This procedure makes it possible to work continuously with a moulding material controllable with ease within very narrow limits.

Some Trends in Steel Metallurgy During 1935

By J. H. G. MONYPENNY, F.Inst.P.

Users of low-alloy steels have shown a tendency to add clauses to their specifications, such as grain size control, freedom from inclusions and use of electrically melted steel. The author discusses these trends, and suggests there is a want of understanding regarding these requirements, and that steels should be selected on the basis of proved properties, not simply as the result of a "popular fancy."

THE last twelve months have been marked not so much by startling discoveries in steel metallurgy as by steady progress in the development of certain types of steels and by a noticeable trend towards certain ideas as to properties of steels, these properties being associated with steel-melting conditions.

Considering first the alloy steels so largely used in automobile construction and also, it may be noted, to an increasing extent for other engineering purposes, the tendency, noticeable for some years, on the part of users to demand cheaper steels possessing really good mechanical properties, has still continued and has been met by the steel makers with low alloy steels of quite reasonable cost, possessing remarkably good tensile and impact properties. Generally, of course, these properties are only obtainable in full measure in bars or forgings not exceeding certain maximum sizes, above which mass effects become increasingly apparent, but within these limits of size, such alloy combinations as manganese and molybdenum, chromium and molybdenum, or manganese, chromium and molybdenum together, in judicious amounts but with a total alloy content (including manganese) of about 2½% or less, have enabled steel makers to offer extremely good combinations of high tensile strength (*e.g.*, up to 65–70 tons per sq. in.) and toughness. Many of the steels so produced—though not all—are free from ordinary temper brittleness effects, a factor which simplifies their heat treatment.

When material is required having still higher tensile strength—*e.g.*, in the range of about 65–85 or 90 tons per sq. in.—together with good toughness values and relative freedom from mass effects, the demand continues to be met as a rule by nickel-chrome-molybdenum steels. Sometimes the molybdenum is replaced by vanadium, but the former is the more frequently used, and is definitely preferable on account of its action in eliminating temper brittleness, an advantage not possessed by vanadium.

Molybdenum would appear to be one of the most useful alloying metals which the steel maker has at his disposal. Apart from its use in producing high tensile steels as indicated above, it is also one of the best alloying elements for increasing the strength of steel at high-steam temperatures. Sometimes it is added without other alloys, but in other cases—*e.g.*, for highly-stressed bolts for which material with high-tensile strength is demanded—it is generally combined with chromium, sometimes with nickel in addition. Chrome-molybdenum steels, however, are definitely preferred by many engineers to the nickel-chrome-molybdenum type for bolts exposed to high-steam temperatures; if of suitable analysis they are extraordinarily free from embrittlement after prolonged sojourn at such temperatures and tests show them to be at least as strong at these high temperatures as the nickel-chrome-molybdenum type. It may be noted also that chrome-molybdenum steels of suitable composition respond in a very useful manner to the nitriding process.

During the last twelve months an increasingly noticeable tendency has been evident among users of low-alloy steels, and also to a certain extent of carbon steels, to add new clauses to their specifications. This tendency has been evident mostly in the automobile and aeronautical industries, the added clauses being concerned with :—

(*a*) grain size control.
(*b*) freedom from inclusions.
(*c*) use of electrically melted steel.

It may be well to consider briefly what these demands mean and what benefits they are likely to confer.

Grain Size Control

If one were to judge from the technical press, grain size control would appear to have been an almost exclusive product of the United States; actually, however, it has been practised in this country for some time by certain firms as a means of obtaining improved properties, notably increased toughness, in carbon steels and some low-alloy steels. Its use, however, has not been widely boomed in the technical press—or in advertising matter!—as appears to have been the case over the water. Probably attention was first drawn to the differences in behaviour, during certain heat-treatment operations, which might exist between steels of apparently identical composition, in 1922 in a paper by McQuaid and Ehn, on "Effect of Quality of Steel on Case-Carburising Results." It was apparent from this paper, and others which followed, that two steels of apparently identical analysis, if subjected to certain forms of heat treatment, might become fine grained and coarse grained respectively, and that, if so, the latter type possessed deeper hardening qualities. In the paper by McQuaid and Ehn, this last feature assumed great importance owing to the type of steel used—case-hardening steel of relatively low manganese content—and hence the coarse-grained steel was labelled "normal" and the other "abnormal." It is quite likely that if the steels used had contained more manganese—and hence possessed deeper-hardening capacity—the descriptions would have been reversed as the finer steel would have hardened adequately and also possessed greater toughness than its coarse-grained fellow. The production of steels which retained a fine grain size under heat-treatment conditions—*e.g.*, carburising for four to eight hours at 900–925° C.—which might be expected to produce a coarse structure, attracted considerable attention, and it was soon evident that such steels could be obtained by the addition of aluminium and some other deoxidisers (*e.g.*, zirconium and titanium) before or during casting. The indiscriminate use of these deoxidisers, however, did not necessarily give the desired effect; the latter was only obtained when the deoxidation of the steel had been carried to a suitable stage in the furnace before the aluminium was added in the ladle or mould. The theory generally held (although there are some aspects of the matter which seem difficult to reconcile with it) is that the added aluminium (or, at least, part of it) exists as a very fine—probably submicroscopic—dispersion of alumina and that these fine particles provide nuclei for the formation of numerous very fine austenite grains at Ac 1, and also prevent any appreciable grain growth—up to some limiting temperature—after the mass has become wholly austenitic at Ac 3. It is the need for this qualifying phrase which provides a difficulty for the alumina dispersion

theory; these "fine-grained" steels generally retain their fine structure up to some temperature—may be as high as 1050° C.—but above this they may become suddenly very coarse. This behaviour would suggest possibly that the alumina particles become soluble in the steel at the given temperature or that the tendency in the steel to undergo grain growth becomes eventually so strong that the alumina particles are unable to restrain it.

It may be noted at this stage, that additions of certain carbide-forming metals—*e.g.*, tungsten and vanadium, appear to have a similar restraining action on grain growth over a limited temperature range and due probably to the sluggish rate at which their carbides dissolve above Ac1. The effect of fine particles in retarding grain growth in metals is not new; for example, the addition of thoria to the tungsten used for the manufacture of electric-lamp filaments is regularly practised to prevent grain growth in the heated filament and thereby prolong its life.

Whatever the cause, certain firms both in this country and in the United States, have offered to their customers steels possessing certain properties not always associated with material of similar analysis. Frequently, at least in this country, the particular virtue of these specially produced steels, to which attention has been drawn, has been a high impact value. They have other characteristics, however; thus they harden less intensely than steels of similar analysis which easily coarsen and they are less liable than the latter to warp or crack during hardening operations. Other properties which have been claimed for them, though less well demonstrated, are that they flow more readily in forging, and are less embrittled by cold work. Against these advantages, it is claimed—more particularly in the United States—that they are less readily machined than the coarse-grained steels, though this is stated to be overcome by normalising them, before machining, at a temperature sufficiently high to produce a coarse grain, a fine structure being subsequently restored by appropriate heat treatment. Such steels being offered to users, it has almost inevitably happened that the latter, finding the steels to possess desirable properties, have turned their thoughts towards specifications involving some sort of grain-size test, and it would appear from a perusal of some of these specifications that their authors do not appear to have a very clear idea of what their grain size requirements mean or what advantages they will derive from them.

First of all, it does not seem to be clearly understood that the grain size which is controlled is that of the austenite grains existing at certain high temperatures above Ac 3; whatever method of test is used should allow this grain size to be determined definitely and easily. Herein lies one advantage of the standard McQuaid-Ehn test; the size of the austenite grains produced by heating for eight hours at 925° C. is clearly shown by the cementite network existing in the carburized zone. A grain count under such conditions is easy and may be contrasted with the request of an optimistic individual for a grain count in an hardened and tempered sample of nickel-chrome steel of the S. 65 type. What information does such a test as the McQuaid-Ehn convey? Merely that under the conditions of that test, the austenite grains of the particular steel had a certain grain size. If the steel tested has actually to be carburized in practice, the test indicates the likely grain size of the carburized case after the carburizing operation, providing this is not longer or at a higher temperature than the test conditions. If the steels are not to be carburised but merely normalised or hardened and tempered (these treatments being normally carried out at lower temperatures than 925° C.), they will probably show when so treated differences in grain size similar to those in the McQuaid Ehn test but of a lower magnitude. Where large numbers of parts have to be so treated, a steel possessing a fine-grain size under the McQuaid-Ehn test may therefore, be looked upon as being more fool proof than a coarse-grained steel, particularly to a user who doubts the accuracy of his furnace temperature control. It does not by any means follow, however, that such a steel will have a fine grain size when drop stamped or forged, as some people seem fondly to imagine; on the contrary, the "fine-grained" steel may be quite as coarse as, or even coarser than, the "coarse grained" steel.

One suggested specification which the writer has seen requires that a microsection cut from the heat-treated test piece used for the acceptance tests shall possess a fine grain. What possible value is this to the purchaser?

If the material is being supplied in the heat-treated condition, the actual results obtained from tensile and impact tests either fulfil or not the specified requirements; if they do, it would seem a matter of quite minor importance to the user whether the grain size *of the piece tested* is finer or coarser than some arbitrary standard.

On the other hand, if the material is supplied as a semi-finished product, the microscopic examination shows whether the required physical properties are obtained with a somewhat coarser or finer grain size. What does the user, who presumably has subsequently to heat-treat the bulk of the steel himself, gain by the information? Generally speaking, such inspection test pieces are heat-treated under laboratory conditions; if the purchaser can operate the furnaces in his heat-treatment department under equally good conditions, he may expect to get similar mechanical properties and an equally fine or coarse grain, as the case may be. The test, however, gives him little or no information as to the probable results of less good heat-treatment conditions. One may suggest that such a grain-size requirement adds little or nothing to the information which is obtained from the specified tensile or impact values.

By contrast, the possession of a fine grain in the McQuaid-Ehn test is some indication that the steel will have a fine-grain size after any normal heat-treatment operation, even if the temperature control in the latter is not of the best.

Assuming, however, that with a knowledge of the manner in which the steel is to be fabricated and heat treated by the user, a reasonable grain-size control test has been evolved, it may further be asked whether the tendency to produce fine grain steels is altogether good. Generally, it may be assumed that such steels are produced by the addition of aluminium as indicated earlier; if the theory generally held is correct, the virtues they possess are due to a very fine dispersion of particles of alumina. It is hardly likely that the final addition of aluminium in the ladle or mould reduces the amount of pre-existing slag particles in the steel; it probably adds to them at least the fine alumina particles, though the latter may be so small as hardly to be visible microscropically. It may also add larger, easily visible alumina particles if the steel were not in good condition when the aluminium was added. It is interesting to follow up this line of thought when one also bears in mind the general demand nowadays for "clean steel." Presumably the measure of the latter is the number of microscopically visible particles of slag in a certain area at a specified magnification, and the steel maker is required to produce steel as free as possible from such particles. On the other hand, if the possession of a high-impact value obtained by producing in the steel an innumerable cloud of fine, microscopically invisible, particles of alumina, is to be desired, one is tempted to ask at what size an inclusion changes from a thing of value to one to be abhorred. Is there some special virtue in a size just too small to be easily discernible at a magnification of 500 diameters or so, or—perish the thought!—is it merely a case of "what the eye doesn't see, the heart doesn't grieve about"!!

One can appreciate for example, the attitude of firms producing engine components which are very highly stressed and who say that a slag particle is a discontinuity in the steel and hence likely to help in the initiation or the more rapid propagation of a fatigue crack. One may ask, however, whether a relatively small number of such discontinuities which happen to be visible under certain microscopic conditions is likely to be so much worse than

a great number of discontinuities, smaller in size but otherwise probably very similar, which are not visible under like conditions. It is quite true that grain size control is more generally applied at present to carbon or low-alloy steels not generally examined so closely for slag particles, but it is not confined to such steels; the author has seen grain-size requirements in connection with more highly alloyed steels (*e.g.*, nickel chrome and 5% nickel) of the type which are often examined closely for freedom from slag. It seems clear that the two ideas of fine grain size and clean steel cannot be unconnected, and the author would suggest that at the present state of knowledge, specification makers would be well advised to ask themselves precisely what they mean by "clean steel," how they propose to measure it, and whether the inclusions they can see easily with the aid of a microscope may be of greater or less importance than those they cannot. Similarly in the case of grain size requirements, they should consider whether the measurements and tests for which they ask—and for which they will eventually have to pay, as all extra tests add to the cost of the steel—really give them valuable information not obtainable from the other specified tests and which can be usefully applied in the subsequent treatment of the steel.

Electrically Melted Steel

Finally, there is the question of electrically-melted steel, and the "popular fancy" for it which has been particularly noticeable during the last year or so among the engineering fraternity. Let it be said at once that extremely good steel can be produced in furnaces which are heated electrically, particularly those of the arc type. It is possible in the latter furnaces to obtain slag conditions and furnace atmospheres which cannot at present be obtained with any other type of furnace, and these specific conditions may be highly desirable in making high-class steel. But the fact that steel is melted electrically is in itself no criterion that it is of superlative quality—it may be quite the reverse, depending on the skill of the steel melter. If the electric furnace is simply used as a convenient means of melting certain raw materials—as generally happens with the high-frequency furnace and sometimes with the arc furnace, more particularly when the latter has an "acid" bottom—the product depends on the quality of the raw materials used and the skill of the melter in deoxidising the bath of molten steel and pouring it into properly designed moulds at a suitable temperature and rate; it may be no better than, or even not as good as, high-quality acid open-hearth steel. If the electric furnace is skilfully handled, however, and this applies more particularly to the basic arc furnace, steel may be produced from it having certain special attributes which are not to be found in the highest quality acid open-hearth steel. For example, if the user wishes to have steel containing very low amounts of sulphur and phosphorus—of the order of 0·01 or 0·02% each—it may be produced for him in the basic-arc furnace, though whether the steel is thereby one whit the better, for the purpose for which it is to be applied, than acid open-hearth steel containing 0·035 or 0·04% each sulphur and phosphorus is another matter. Steel can also be produced in the arc furnace with the amount of visible non-metallic inclusions reduced to a very small amount; one wonders sometimes, however, whether this also applies to inclusions of sub-microscopic size, though perhaps one might take heart from the properties of steels with "controlled grain size" and consider that inclusions may be bad only when they can be seen. And then there is that thorny problem of "snow flakes," which has figured so much of late in technical literature; many observations have been recorded, often apparently of a contradictory nature, and not a few theories evolved. One observation, however, seems to have received fairly general agreement, namely that snowflakes appear to be more prevalent in steels produced in the basic-arc furnace than in those melted in the acid open hearth. The note the author would strike in this matter, as with "grain-size control" and "clean steel" is one of caution. Certain types of steel can only be melted electrically; other types can also be made quite satisfactorily in open-hearth furnaces, and generally at a cheaper cost than similar material electrically melted. The author is convinced that for many purposes for which high-quality high-tensile steels are required, well made acid open-hearth steel is perfectly satisfactory; in some cases the electrically melted product may be superior but if so, it should be selected on the basis of proved properties and not simply as the result of a "popular fancy."

Special Steels

Turning now to the more highly-alloyed steels, those of the corrosion-resisting and heat-resisting types are being used in increasing quantities. No striking development has occurred during the last twelve months; the position has been one of improvement in the qualities of some of the steels and of wider range of uses. A greater facility in processing the steels is observable and among the improvements may be mentioned that concerning the quality of the surface finish of sheets. Extremely good "mirror polishes" are being produced on sheets by some of the steel-making firms who have equipped their shops with the latest types of polishing machines. In particular it may be mentioned that one brand of austenitic steel of the "weld-decay-free" type is available in sheets possessing bright polished surfaces, though other brands still appear to be offered only in the dull polished form.

Developments of the new, practically carbonless magnetic alloys possessing extraordinarily high values of remanence and coercive force still continue. Possibly the iron-nickel-aluminium type is most used at present, but finality is not yet reached, and still higher properties are claimed for some of the newer complex alloys. The production of these remarkable alloys has enabled marked progress to be made in those specialised industries which require magnets of small size but possessing intense magnetic fields.

Some of these types of carbonless alloys also function remarkably well as cutting tools owing to precipitation hardening effects which give the alloys high hardness values, the latter moreover, possessing greater stability on reheating than hardened high-speed steel. Probably the use of such alloys as specialised cutting tools has not developed so rapidly as that of the highly magnetic type, but it may not be less sure on that account; those who are convinced of the usefulness of such alloys may take heart from the fact that the use of tungsten-carbide tools—*e.g.*, "Widia," also progressed slowly at first.

Canada's Mineral Production in 1935

ACCORDING to a statement made by Mr. J. McLeish Director, Mines Branch, Ottawa, at the recent annual western meeting of the Canadian Institute of Mining and Metallurgy, held at Vancouver, Canada's mineral production this year will reach a total value of about $300,000,000, a gain of 8% as compared with the 1934 total of $278,000,000. The 1935 production value will have been exceeded in previous years only once, namely, in 1929, when the figure reached $311,000,000. Metal production will contribute more than two-thirds of the total value for the year, and half of this will be in gold.

The increased value this year has been due almost entirely to the greater output of metals, and gold, copper and zinc are expected to attain new records in quantity production. The production of gold will probably exceed 3,200,000 ounces; copper, 420,000,000 lbs.; and zinc, 314,000,000 lbs. Nickel, lead and the platinum group of metals will closely approach, if not exceed, last year's output. In this connection it should be recalled that Canada has now become the world's leading producer of platinum, palladium, rhodium and iridium, etc., last year's production having reached $6,190,000.

Progress in Design and Application of Electric Furnaces

By H. KNIGHT, B.Sc.

Recent developments of electric furnaces show the remarkable strides made in this direction during recent years, and indicate the large field embraced in present-day electric heating. In this article only brief descriptions of some of these developments are given, but improvements continue, all tending to make the electric furnace an efficient and economical method of industrial heating.

DURING recent years, developments in electric-furnace manufacture and technique have been largely in the direction of improving equipment already in industrial use. Although it is only about twenty-five years since the first electric steel-melting furnace was constructed in this country, yet, in this comparatively short space of time, electrical heating has become one of the foremost factors contributing to the industrial progress of the present day.

It is in the melting of high-grade ferrous and non-ferrous metals that progress has been particularly noticeable, and the rapid rise of the high-frequency furnace in the space of ten years from an experimental appliance to the large installations of the present day, provides a typical example of the progress made in this direction. Furnaces of this type now in use vary from small laboratory sizes of 20 lb. each to large furnaces capable of an output of five to six tons per heat, which combine the advantages of high-frequency melting with quality refining. Purification is considerably assisted by the swirling action induced in the metal by the high-frequency current which brings the metal and slag in continual and intimate contact. This capacity for quality refining of molten steel constitutes the most recent advancement in high-frequency furnace technique, as, before the advent of large furnaces of five tons capacity, high-frequency heating was used principally for melting.

Fig. 1.—Layout of high-frequency installation at the works of Messrs. Samuel Fox and Co., Ltd., Stocksbridge, Sheffield, showing 5-ton furnace during pouring.

High-quality steels for aircraft and automobiles and other high-duty purposes, heat-resisting steels, "nitralloy" steels, stainless steels, etc., can all be made in the high-frequency furnace under the most exact control, and tests made on stainless steel made by this method have proved it to meet the most rigid specifications. An example of the extreme degree of control possible in the high-frequency furnace is provided by the fact that stainless steel with only 0·05% carbon can be produced regularly.

The largest high-frequency furnace in this country has been installed by the Electric Furnace Company of London at the works of Samuel Fox and Co., Ltd., Stocksbridge, Sheffield. A brief description of the plant may be of interest.

Large High-Frequency Furnace Installation

Two furnaces, one of 5 tons and the other of 2 tons (Figs. 1 and 2), comprise the high-frequency installation at this plant, both furnaces being constructed for tilting forward or backward, which allows slag to be removed at one side and metal at the other, thus preventing contamination of the metal by the slag. The motor-generator set is housed in a substation 80 feet from the furnace and the condenser plant situated beneath the working platform. The generator is driven by a motor taking its power from a three-phase, 50-cycle supply at 11,000 volts. The alternator consists of two 625 kW. stators with a common rotor, each stator consisting of two halves, so that it is possible to control the voltage of each of the circuits independently and operate the two furnaces at the same time. If required, the stators can be connected in series, thus applying the full 1,250 kW. to one furnace.

Completely automatic control is provided and protective devices have been incorporated whereby any failure of cooling water to the coils or undue heating will be immediately indicated by coloured lamps, whilst at the same time the current is cut off by the operation of relays. Fullest use is made of the heat in the furnace after each cast, and the time elapsing between the end of pouring of one heat and the beginning of the next has been cut down to a minimum. In a full day's run the current was switched off for about six minutes per heat, and this time includes that required for pouring and recharging the furnaces. This installation represents typical modern high-frequency furnace practice and incorporates in its construction the most recent developments in this direction.

"Double-Furnace" Melting

In many modern high-frequency furnace installations, consisting of more than one furnace (of smaller size than those just mentioned), it is now the practice to operate them off the same control set, the current being supplied to any furnace by means of a change-over switch on the front of the control panel. In a recent installation this procedure is adopted on a 10-cwt. and a 5-cwt. furnace, which are rated at 200 kW.

Fig. 2.—Showing a melt being poured from a 5-ton high-frequency furnace at the Stocksbridge Works.

These two furnaces, working independently can maintain a steady supply of ingots according to their individual output, but occasionally a request may come from the foundry for an ingot or casting, the weight of which exceeds that of the maximum charge from the larger furnace. To meet an emergency such as this, a method has been devised whereby the two furnaces can be in use at the same time and produce a molten product of 15 cwt. or more. This procedure has been called, for the sake of the present article, "Double-furnace" melting and must not be confused with "Duplex" melting, as the latter refers to a process entirely different. The method of operation is quite a simple one and may be described briefly as follows;

The 10-cwt. furnace is charged and the current put on, being kept at full load until the charge is molten. Meanwhile, the 5-cwt. furnace is being charged. When the charge in the 10-cwt. furnace is completely molten, the current is cut off and the electric power is put on the other furnace by a change-over switch. Current is switched back to the 10-cwt. furnace as soon as the charge in this shows any signs of becoming solid. This procedure is continued until the correct casting temperature is attained in both furnaces, and at this point the supply is switched off and both melts poured together. The accompanying diagrams and table show typical heats of stainless steel made in this way. (Fig. 3 and Table I.).

TABLE I.

HEATING TIMES OF 10-CWT. AND 5-CWT. FURNACES.

10-cwt. Furnace.	5-cwt. Furnace.	Heat 1.	Heat 2.	Heat 3.	Heat 4.
		Hr. M.	Hr. M.	Hr. M.	Hr. M.
ON	—	1 25	1 38	1 45	1 35
—	ON	1 45	0 39	0 40	0 20
ON	—	0 11	0 10	0 12	0 10
—	ON	0 9	0 25	0 9	0 60
ON	—	0 6	0 8	0 7	—
—	ON	—	0 5	0 12	—
Total Time ON	—	1 42	1 56	2 4	2 5
—	Total Time ON	0 54	0 69	0 61	0 60

The combined charges in each heat weighed about 17 cwt. and the power consumption varied from 735 kWHrs. per ton in Heat 1 to 796 kWHrs. in Heat 4.

This method of high-frequency melting takes longer time and consumes more energy than is required in producing an equivalent weight when the two furnaces work independently, and for this reason, is not an economical way of producing say 15 cwt. ingots continually; but, in a foundry usually requiring 10 cwt. and 5 cwt. ingots or both, it does provide a useful means of dealing with an occasional order for a larger ingot. It is not worth installing a 15-cwt. or a 20-cwt. furnace in a foundry usually dealing with 5- and 10-cwt. ingots with an occasional larger one, and in cases like this, the procedure here described is extremely useful.

High-Frequency Hardening

A reference must be made here to an entirely new application of high-frequency induction heating, which gives distinct promise of developing into a process that will prove of tremendous value to the hardening of special shapes and sections. The "Tocco" process of high-frequency hardening is now being developed in this country by the Electric

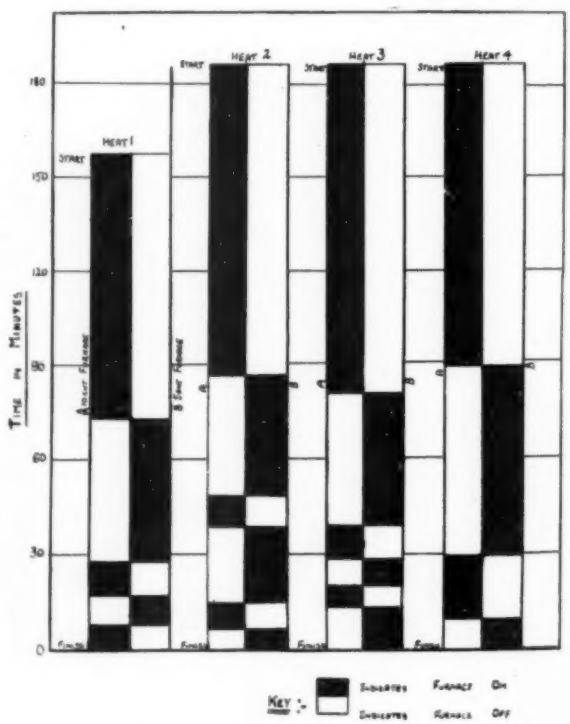


Fig. 3.—Diagram illustrating "Double-furnace" melting.

Furnace Co, of London, and extensive tests on this process reveal that it is ideally suited for hardening selected surfaces of a steel part, for example, the bearing surface of a crankshaft for motor-cars.

For increasing the hardness of some bearing surfaces in a place where other methods would be impracticable, this process is eminently suitable, as the depth of penetration can be regulated with considerable accuracy. By the use of a suitable induction equipment, the designated part is quickly brought up to the hardening temperature, after which it is quenched by a sudden stream of cooling water,

without distortion, as the local heating is so rapid that the main part of the metal is not heated.

A New High-Temperature Thermocouple

To digress a little from the general trend of this article, it would be worth while to make a short reference to a very recent development in appliances for the measurement of high temperatures of molten metal in electric furnaces. In the region at which steels attain their molten state, difficulty has been found in obtaining a thermocouple which will stand up successfully for long periods to temperatures of 1,500° C. and above, and at the same time provide a thermo-electric power of measurable magnitude.

The Société des Electrodes de Savoie has just put on the market a thermocouple of carbon-carborundum which is claimed to provide a suitable means of measuring temperatures at which other thermocouples would be destroyed in a very short time. The Fitterer-Savoie Thermocouple, as it is called, is infusible at temperatures as high as 2,000° C. to 2,200° C., and can be used for the accurate measurement of molten-steel temperatures.

An outstanding feature of the Fitterer-Savoie Thermocouple is its very high thermo-electric power as compared with other thermocouples, both rare metal and base metal, at present in use. Its thermo-electric power increases as a linear function of the temperature, its value rising by 30

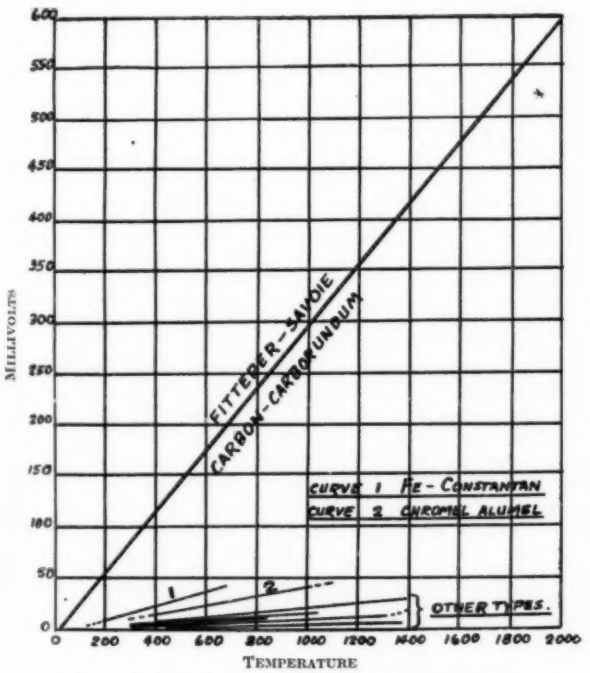


Fig. 4.—Comparison of E. M. F.'s for different couples.

millivolts for each 100° C. increase in temperature, until at 2,000° C. it has a value of 600 millivolts. Such remarkably high millivolt values greatly facilitate accurate determinations of the temperatures of molten steels and other high-melting point alloys, with consequent improvement in the quality of the metal as a result of greater control of grain size. The accompanying curves show the remarkable superiority of this thermocouple over other types. (Fig. 4).

Another of its features is that it undergoes no allotropic modifications during heating, and even after long and arduous service at high temperatures it is characterised by remarkable constancy in millivolt values. Its particular application seems to be in precise temperature control in the region 1,350°–2,000° C.

The Rocking-Resistor Furnace

A recent development in electric-furnace construction has been in the application of resistance-heating to the melting of metals and alloys of high-melting points—*e.g.*, cast iron, brass, and bronze. Resistance-heating has been applied for many years to the melting of low-melting point metals and alloys, such as lead, zinc and aluminium, in furnaces heated by Nichrome resistors.

The new rocking-resistor furnace has been developed

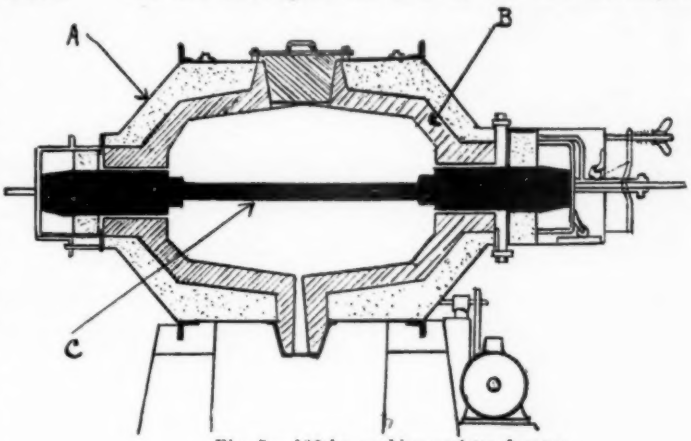


Fig. 5.—100 kg. rocking resistor furnace.

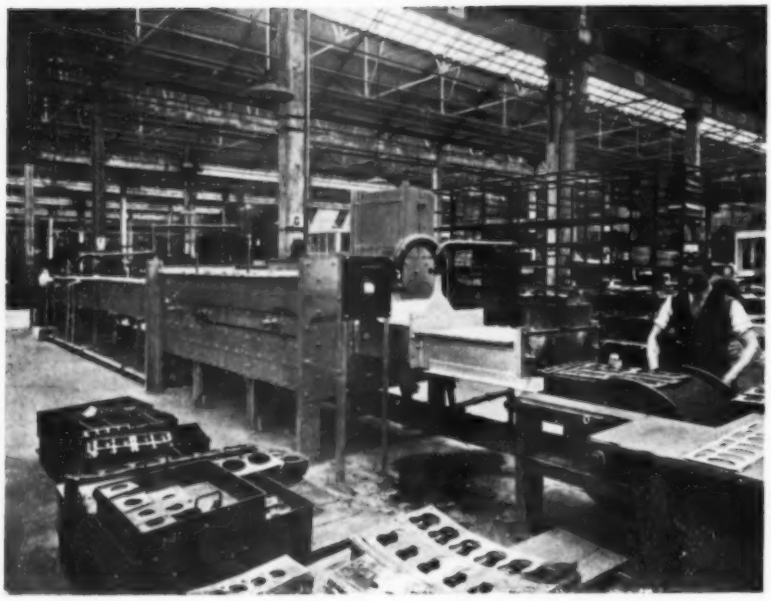
as a result of work done by Monsieur George at St. Gobain, in France, on silica tubes. Indications point to its extensive use in the near future for melting brasses, bronzes and special cast irons.

The furnace consists of a cylindrical shell (A) Fig. 5, with conical ends lined with a heat-resisting material and a refractory (B), which may be acid or basic. The heating element is a graphite rod (C) fixed axially through the furnace in such a manner that it can be removed easily when it requires changing or to avoid the risk of breakage during charging. The furnace shown is a small one of 100 kgs. capacity of 100 kW., single phase. The graphite rod is 35 mm in diameter, weighing 1·32 kgs., and one of its ends is screwed to a cylindrical graphite element, while the other end, which is conical, fits in another graphite element, being kept in position by a spring outside the furnace. Both ends fit into metal collars, which are kept cool by cold water circulating around them.

When this method of heating is applied to larger furnaces employing larger currents, a modification in the construction is necessary to overcome the large eddy current losses in the magnetic parts of the frame, and to maintain a good power factor, which would fall as a result of inductance in the steel body. This is achieved by a copper lining or shield, which is put on the steel frame, thus providing a path for the return of the current after it has traversed the resistor, and so both incoming conductors terminate at the same end of the furnace.

The rocking movement, which is a feature of all these furnaces, greatly facilitates pouring and mixing of the charge thus producing a homogeneous cast. They have distinct metallurgical advantages over arc furnaces, inasmuch as the latter are characterised by intense local heating in the neighbourhood of the arc with resultant volatilisation of certain metals—*e.g.*, zinc, that may be present. Complete control of the atmosphere inside the furnaces can be effected, and melting may be carried out in vacuo.

This type of furnace may be successfully applied in foundries where a wide variety of alloy compositions has to be dealt with, as the furnace body can be easily removed and replaced by another of different lining, if required, thus allowing acid and basic melts to be made at will. No violent fluctuations occur in the molten metal, as is the case in high-frequency furnaces, and easily oxidisable metals and alloys—*e.g.*, aluminium, can be produced in a more satisfactory condition. Coupled with this, are its low cost



By courtesy of Electric Furnace Co., Ltd.

Fig. 6.—Continuous type furnace for bright annealing.

as compared with other electric furnaces, and its simplicity of design and operation. These all indicate that the possibilities of the rocking-resistor furnace are very considerable, and its introduction will prove of immense value to metal manufacturers.

Heat-Treatment Furnaces

The use of electrical heating in the industrial heat treatment of metals and alloys has undergone remarkable progress during recent years and to-day it is applied to all manner of processes requiring accurate temperature control. Remarkable advances have been made in low-temperature treatments that require precise operation within narrow limits of temperature. It is, however, in the realm of the bright-annealing of metals and alloys that progress has been most marked, and nowadays all manner of furnaces are in use that employ some method or other of atmosphere control. The advantages of obtaining fully annealed metals in a perfectly bright condition have been discussed so much in technical literature that no useful purpose will be achieved here by repeating them. Suffice it to say that the use of controlled atmospheres for heat treatment is of tremendous value to modern metal users, as it eliminates pickling and polishing operations with considerable reduction in cost of the finished product.

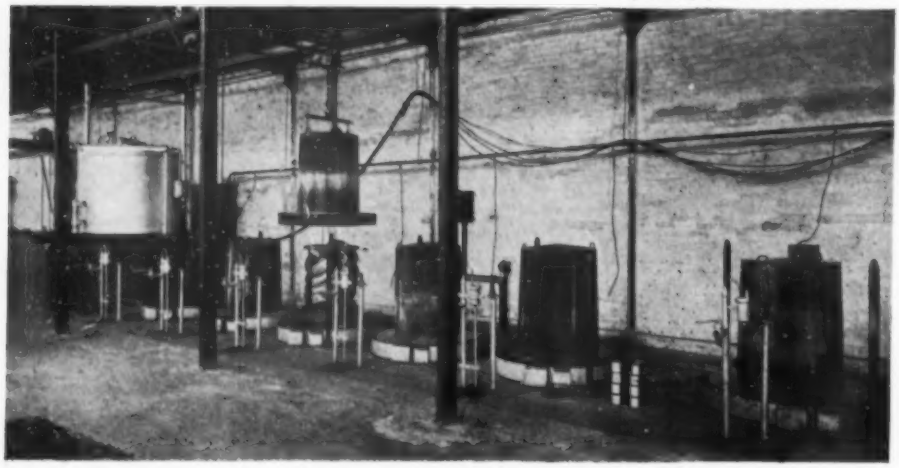
Many kinds of furnace atmospheres are at present in use, and there is no lack of suitable means of retaining bright surfaces during annealing, but the main problem now confronting furnace users is to find the cheapest medium for each particular job. For the bright annealing of non-ferrous metals, either reducing or neutral gases are applicable as protective media, and hydrogen, nitrogen, hydro-carbons, cracked ammonia and burnt mixtures of town's gas and air may all be successfully employed. It is in regard to the last named that considerable progress has been made, and nowadays furnaces employing this method are being constructed on an extensive scale. By arranging the proportions of gas and air, a suitable atmosphere may be produced by combustion, and this may then be passed through a cooler and a system of purifiers for the removal of sulphur, so that the final gas can be introduced into a furnace and act as a protective annealing medium to the metal.

Several types of plant utilising an atmosphere from town's gas are successfully applied to annealing copper, silver, gold and many non-ferrous metals, either in the form of small sections or as strip and wire. In the continuous type, the gas and air proportions in the mixture are regulated so that only partial combustion occurs, with the result that the final atmosphere can burn inside the furnace, with exclusion of air that may tend to leak in at the ends. Fig. 6 shows a typical installation of a continuous furnace used for the bright annealing of copper gaskets for motor-cars.

In the batch-type or "Bell"-type furnace the atmosphere employed is only slightly reducing, and the gas and air contents in the mixture are regulated to give almost complete combustion. An installation consists of a number of bases side by side on to which the material is charged, and the furnace can be lowered over each base when required. The charge is contained in an inverted hood, which rests in water seals in the base, thus effectively preventing ingress of any external oxidising media. A fan is provided in each base, so that constant circulation of the atmosphere is maintained around the charge, thus producing a uniform anneal. Fig. 7 shows one of a number of installations of bright annealing furnaces for the annealing of copper wire or strip in coils. In the former each base can take a charge of 1·8 tons at each heat, while in the latter the maximum charge is about 10 cwt. per heat.

Fig. 7.—Bright annealing installation for copper wire. Capacity of each base, 10 cwt.

By courtesy of Electric Furnace Co., Ltd.



The annealed product from these furnaces has been found to possess excellent properties both from the point of view of colour and softness. For all gauges of high-grade copper in the form of coiled wire and strip, this type of furnace can be installed with safety, as it provides a very cheap and efficient means of annealing non-ferrous metal with a resultant bright finish free from the risk of water staining.

Copper Developments—A Review of Recent Work

By A Special Contributor

Although one of the first metals to be employed by man, copper continues to play a vital part in all branches of engineering science and architecture. So wide is its application that, in this article, it is only possible to review some of the more recent electrical, architectural and metallurgical developments.

TO give a picture of recent developments connected with copper, it is desirable first to draw attention to the low prices at which the metal has been obtainable during the last few years—a result for which the opening of new and very well-equipped mines in the British Empire has been chiefly responsible—so that copper now costs less than one-fifth as much as nickel or tin. The trend of copper prices during recent years has not only been towards a very much lower average price, but the annual variation between the highest and lowest price has been greatly diminished. For example in 1929 the price of standard copper ranged from £98 to £66, whereas for 1934 the corresponding figures were £34 and £25½.

During this period the centre of copper production underwent a profound change. In 1929 out of a world production of nearly two million tons, the U.S.A. produced about 50%, with British Empire sources accounting for only 6%. In 1934 the U.S.A. produced only 17% of the total of one and a quarter million tons, while the Empire produced 26%, of which Canada and Rhodesia each accounted for about 12%.

The year 1934 showed a record consumption of copper in Great Britain at 220,000 tons, and this consumption, from the figures so far available, is being fully maintained during the present year. Though the uncertainty in international politics has probably affected world consumption, this factor has had a negligible effect on home consumption, and the increased consumption does not appear to have been due to any abnormal cause, but rather to the general increase and development in many fields.

Copper roofs on the Athenaeum Club. Contractors, Courtney and Fairbairn, Ltd. Copper craftsmen, Fredk. Braby and Co., Ltd.

DEVELOPMENTS IN ELECTRICAL APPLICATIONS OF COPPER

The electrical industry normally takes about half of the total copper produced, and the recent revival in this industry has no doubt largely contributed to the record sales of copper during the past two years. The supremacy of copper for most purposes as a conductor of electricity is almost unchallenged. As an overhead transmission line material, and to a lesser extent for bus-bar purposes, aluminium has been its only serious rival, but with copper at its present price and in view of recent technical developments, it is becoming increasingly difficult to justify the use of any alternative material for conductor purposes.

Cadmium Copper Conductors

For subsidiary overhead electrical transmission lines and low tension distribution mains, copper conductors are used almost exclusively. For high voltage overhead lines particular attention has recently been paid to the development of copper or copper-alloy conductors which, while retaining all the well-established virtues of ordinary copper conductors, have at the same time enhanced mechanical strength.

An important contribution to this ideal has been the introduction for long-span transmission lines of cadmium-copper, an alloy containing about 0·8% to 1·0% cadmium, remainder copper. This material is particularly noteworthy, since a considerable increase in tensile strength is accompanied by only a small decrease in conductivity as compared with pure copper, while in other respects the alloy is as satisfactory as the pure metal, and in some respects superior. The advantages of cadmium-copper overhead-power line conductors are now beginning to be realised, and the recent production of a British Standard Specification (at present only in draft form) should assist engineers to avail themselves of the benefits which have resulted from the application of this alloy.

The use of cadmium-copper for tramway and railway-trolley wires is also increasing, as is its use for overhead telephone and telegraph lines, for flexible telephone cords and similar cables, for the electrodes of electric-welding machines and many other purposes.

Steel-Cored and Hollow-Copper Conductors. A considerable amount of work has been done recently to develop stranded-copper conductors, reinforced with steel-wire cores for use as overhead transmission-line conductors, and the results of experimental work up to date indicate that conductors of this type can be produced, which are superior to other types of composite conductor at present on the market. Several hundred miles of steel-cored copper conductors are already in service or are being erected in this country.

With the advent of super-transmission voltages, mainly for lines erected abroad, the use of hollow-copper conductors having a large over-all diameter for a given cross-sectional area is increasing. Over sixteen hundred miles of such conductor were recently erected on one transmission line alone in the U.S.A. Lines employing hollow-copper conductors are also being erected in Sweden and other parts of Europe and are under consideration for a very large

Copper rainwater gutters and downpipe at "Gayles," Friston, Sussex.

system of electrical interconnection to be constructed in the U.S.S.R., which may operate at a voltage more than three times the 132,000 volts adopted for the Grid system in this country.

Marine Applications. In normal times the shipbuilding industry is one of the largest consumers of copper, and although the tonnage of shipping built in this country has decreased compared with past years, the increasing tendency to adopt electric drive for all auxiliaries, and in some cases for propulsion as well, has done much to maintain the consumption of copper in the industry.

Many hundreds of tons of copper are installed in a ship such as the *Queen Mary*. When electrical propulsion is also adopted, and there are now nearly half-a-million tons of electrically-propelled shipping, including such liners as the recently completed all-electric *Normandie*, the quantity of copper consumed is even greater. Some idea of the size of the electrical installation of the *Normandie* and of the amount of copper used in it, may be gained from the fact that the generating plant installed would be sufficient to supply the electrical requirements of a city of the size of Glasgow. In addition to the electrical equipment a very considerable quantity of copper is also required for other engineering parts and general fittings. Over one hundred tons of copper-alloy tubes, for instance, were supplied for the *Normandie's* main condensers, while the finished weight of the four bronze propellors alone is about 93 tons. The total finished weight of the *Queen Mary's* four bronze propellors is about 146 tons.

Copper-Oxide Rectifiers. Among the many other applications of copper for electrical purposes may be mentioned the developments which have been taking place in connection with copper-oxide rectifiers. Such rectifiers are employed for the purpose of converting alternating current to direct current and incorporate discs of copper coated with a layer of oxide. In addition to their use for light current purposes, they are being used with success for heavy current applications, such as for electro-plating, as well as for very high voltage work, such as the operation of X-ray apparatus.

There is also an indication that the sensitiveness of the electrical resistance of a copper-oxide film to variations in temperature may lead to important developments in connection with the use of "cuprox" rectifiers for thermal relay purposes.

The versatility of a copper-oxide film has been further demonstrated recently by the exploitation of its light sensitive properties. Copper-oxide light sensitive cells are a comparatively recent development but promise to play an important part in the construction of meters for the measurement of light intensity and in similar apparatus.

A copper disc coated with a film of red oxide and covered with a layer of conducting varnish is sensitive to the incidence of light which gives rise to an electro-motive force which varies both with the intensity and wave-length of the light. Such a cell is particularly useful as a means of measuring illumination intensities as its response to the wave-length of the incident light is approximately the same as that of the human eye.

Copper Conduits. The use of copper conduits for electrical wiring installations is increasing. Several important installations have been carried out recently, and it is being realised that the employment of copper tube for such purposes not only has many technical advantages but results in a considerable reduction in installation costs, sufficient to make the system strictly competitive with others at present on the market. Copper conduits will undoubtedly find an ever-increasing sphere of application, particularly in factories and other locations in which the atmospheric conditions are such that ferrous tubes become rapidly deteriorated.

ARCHITECTURAL APPLICATIONS OF COPPER

The use of copper tubes and pipes is extending rapidly in plumbing for water-service work and sanitation, where the economic advantage of the low price of copper has been further strengthened by the development of jointing methods enabling thin-walled tubes to be used, so that copper installations can be carried out as cheaply, and in some cases more cheaply, than in other materials.

These jointing methods, which have superseded to a great extent the use of thicker tubes with screwed connections are (*a*) compression fittings (*b*) bronze-welding and (*c*) capillary or soldered joints. "Compression" joints are universally applicable and so satisfactory as to have led to the introduction of more than twenty different types of these mechanical joints, which, while comparatively costly in themselves, are economical in time and labour of fixing. Bronze welding is going ahead rapidly after the solution of certain problems hitherto attending the welding of copper, and the system is found to be particularly successful in large-diameter pipes as used for sanitation, and can be very economical where a certain amount of repetitive bench-work is practicable. The newer "Capillary" joints, employing tin-base solder and recently introduced from America and the Continent, are making rapid strides, and are convenient and economical in time, labour and materials.

It is significant that copper-water piping is now used, not only in districts where the composition of the water in its effects on other metals makes the use of copper imperative, but all over the country as much for municipal and state-aided work as for the more costly type of building.

Apart from the fact that the metal is so very lasting and resistant to corrosion, thus saving the cost of painting and maintenance, copper tube offers such recognized advantages in its smooth bore, ductility, rigidity in long lengths, etc., that it is now applied, jointed by similar methods, to all pipe-line services in building, such as gas-pipes and electrical conduits already mentioned.

Among the applications of copper sheet and strip, the historical one of roofing appears prominently. The progress of copper roofing in this country is understandably slower than that of tubing and pipes, owing to such factors as the wider choice of alternative materials and the strong entrenchment of traditional materials such as clay tiles, which have low first cost. Nevertheless, British architects are beginning to take a leaf from the book of such countries as Denmark and Sweden, where copper is almost invariably specified for buildings of any size or importance because of its lasting qualities, attractive appearance and low maintenance costs. Copper is equally suitable for sheathing

either flat, sloping or vertical surfaces, and this quality, almost unique among roofing materials, is important, particularly in view of the architectural trend towards the flat or low pitched roof. Methods have now been developed which show promise in the rapid production of the naturally protective pale green patina which forms on copper roofs.

Copper rainwater gutters and downpipes are a valuable utilisation of the material which is arousing new interest. Apart from the saving in paintwork effected by the use of copper, weight is saved by comparison with cast iron by the use of quite thin strip of 20 or 22 S.W.G. adequately supported. Damp-proof courses of annealed copper strip have been adopted, the material being obtainable in long lengths which reduce or eliminate joints, and ready-cut in usual wall widths. As compared with other available materials, copper strip of this type has the advantage of being easily laid in alignment, can be jointed at angles by a simple overlap, adjusts itself to inequalities in the bed and settlements without fracturing, is resistant to corrosion by lime or cement mortar, and cannot, of course, "squeeze out"; 24 S.W.G. thickness is recommended. Drips, cills, etc., can economically be carried out in copper strip with equal advantage.

There is a growing appreciation of the fact that copper provides a useful and now economical sheathing or protection for structures or materials which have themselves indifferent powers of resistance to corrosion and the elements. The availability of copper-faced plywood for such purposes as external doors is an example, and copper-sheathed buildings will doubtless be seen in this country in the near future, as they are elsewhere. The problem is now, however, one of architectural design rather than metallurgical, as the suitability of copper in general principle has already been proved beyond doubt.

Copper boilers, cylinders, and tanks have been available for many years and have been valued, particularly in hot-water installations, for obvious reasons. Here again there is a noticeable increase due to low prices, and the move to standardise these articles will no doubt lead to their still wider application.

The use of copper alloys in the form of extruded and drawn mouldings in the architectural metal-work of such buildings as the R.I.B.A. Headquarters and the new Underground Stations is noteworthy. A factor is the contemporary revolt from "decoration for its own sake," on the insistence that mouldings and other "trim" should perform some structural function, and not be merely stuck on for effect. Extrusion of copper alloys produces many important building components, such as sections for non-rusting window and door frames and other glazing, ties for cavity walls, etc.

There is a growing appreciation of the decorative possibilities of the warm and cheerful colour of copper and of the golden colours of its alloys such as the gilding metals. Low prices are creating a demand for innumerable types of small household articles such as ashtrays, vases, cooking vessels, door furniture and lighting fitments, etc., and in the form of tubes, for furniture and other equipment, while many copper objects of more decorative than utilitarian value are to be seen in shops which specialise in interior decoration, testifying to a revival of interest in the metal as a decorative medium.

METALLURGICAL DEVELOPMENTS

In the metallurgical field, perhaps, most progress has been made in connection with the applications of copper in the iron and steel industry and hence a general review and survey of progress made during the past year in this one particular section—until recently an unimportant one from the point of view of consumption of copper—may be of greater interest than a general survey covering the more familiar non-ferrous alloys. The publication of Gregg and Daniloff's bibliography of "Alloys of Iron and Copper"[1] in the Alloys of Iron Research Monograph Series has served to draw general attention to the effects of copper upon ferrous alloys.

Copper in Low Carbon Structural Steels

It is now almost twenty years since the American Society of Testing Materials initiated corrosion tests upon copper-bearing steels and their experience, coupled with that of users of the material, has led to an ever-widening application of copper in structural steels, the preferred amounts being of the order of 0·25% to 0·50%. The advantages of copper-bearing steels in applications subject to corrosive conditions, as in roofing, gasometers, air-conditioning plant, etc., are now well established and the output of copper-bearing steel for such purposes has been considerably expanded within the last few years; in this country comparative trials are now being made under the auspices of the Iron and Steel Industrial Research Council.

Quite recently it has been found that the corrosion-resisting properties of copper steels are further improved by the presence of phosphorus. Daeves[2] has reported very beneficial effects as the result of Phosphorus additions up to 0·3% and a proprietary American steel "Cor-Ten"[3] contains both copper (0·3% to 0·5%) and phosphorus (0·1% to 0·2%) in addition to other elements.

When alloyed with copper and small amounts of certain other elements it is possible to obtain cheap alloy steels, which possess advantages due to improved corrosion resistance and which are also of superior mechanical properties, and it is of interest to note that the copper-chromium, copper-manganese, and copper-molybdenum steels which are widely used in Germany for constructional purposes and which are known as St. 52 (D.I.N.), are of this type. They have approximate compositions of:—

(1) carbon, 0·15%; copper, 0·5–0·8%; chromium, 0·4%; manganese, 0·7–1·0%; silicon, 0·3–0·5%.

(2) carbon, 0·15%; copper, 0·3–0·5%; manganese, 1·2–1·6%; silicon, 0·3–0·5%.

(3) carbon, 0·15%; copper, 0·4%; manganese, 1·0–1·6%; molybdenum, 0·15–0·25%.

A recent specification of the British Standards Institution[4] standardises high tensile structural steels of carbon content up to 0·3% for bridges and general building. The tensile strength of such steels is 37–43 tons per sq.in., and the copper content may be up to 0·6%. Generally these steels have a chromium content of about 0·5%–1%.

1%–1½% Copper Steels

The addition of upwards of 1% of copper to low-carbon steels confers marked precipitation-hardening properties on reheating to temperatures of 450°–600° C. for controlled periods[5]. This feature has been confirmed by practical tests in this country but has not yet been exploited commercially, although by cold working soft strip it makes possible the fabrication of complex pressings and other components which may afterwards be endowed with enhanced and comparatively uniform hardness by heat treatment.

The Republic Steel Corporation of U.S.A.[6] have recently marketed two types of low-carbon alloy steels of copper content of 1·3–1·4%; at the same time 0·75% of nickel is present in order to improve the hot-working properties. Both the yield point and tensile strength are very favourable, being up to 32 and 40 tons per sq. in. respectively, and the use of these alloy steels in sheet and other forms for such purposes as rail waggons has permitted weight reductions of 25%; at the same time there are improved corrosion-resisting properties.

Other Copper Steels

Copper has also been added to many other types of steels, and in the case of copper additions to high-carbon

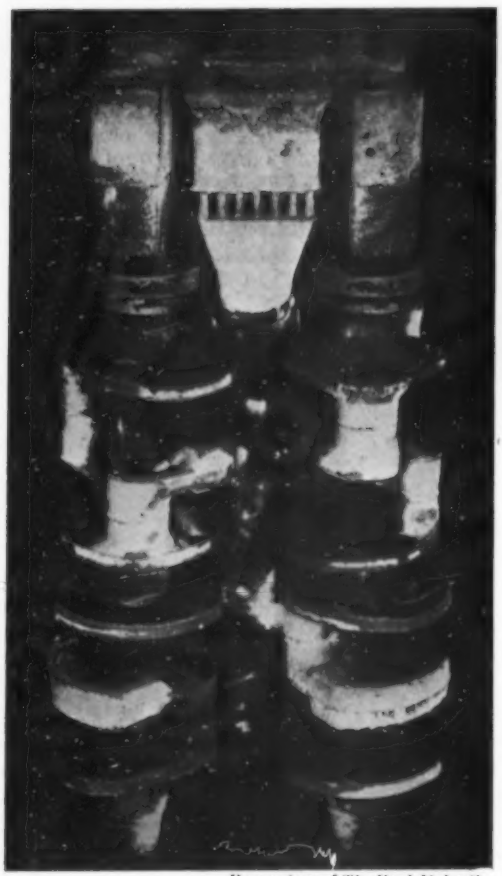
1 J. L. Gregg and B. N. Daniloff, "Alloys of Iron and Copper." McGraw-Hill Book Co.

2 K. Daeves, *Arch. Eisenhuttenwessen*, 1933–6, 9, 37.
3 G. N. Schramm, E. S. Taylerson and A. F. Striebing, *Iron Age*, 1934, Dec. 6. p.33.
4 British Standards Institution Specification No. 548, May ,1934.
5 C. S. Smith and E. W. Pfamer, *Amer.Inst.Min.Met.Eng.*, 1333, 105, 133. F. Nehl, *Stahl und Eisen*, 1930, 50, 678.
6 H. L. Miller, *Metal Progress*, July, 1935, 28.

tool steels it has recently been shown that the presence of 0·25% copper results in a much greater depth of chill upon quenching[7]. For small rolls, suitable for the rolling of precious metals, Krupp have employed high-carbon copper steel of approximate composition[8]:—

Carbon, 0·80%; silicon, 0·25%; manganese, 0·30%; phosphorus, 0·05%; copper, 0·25–0·30%; and an extension of the use of copper in such types of high-carbon steels can be anticipated. Steels containing 0·5%–0·6% carbon and 0·25%–0·50% copper, are also being developed for high-tensile wire ropes, to obtain diminished rusting.

A large amount of experimental work has been under taken with the iron-nickel-copper series of magnetic alloys. Dahl, Pfaffenberger and Schwartz[9], Koster and Dannohl[10] and Auwers and Neumann[11] have investigated the magnetic and other properties of this group, which is outstanding in regard to easy workability. Recently it has been announced that the Alleghany Steel Company of U.S.A. are commercially exploiting a copper-nickel-iron alloy for radio transformers, as it ensures a more natural tone[12].



Group of four automobile castings

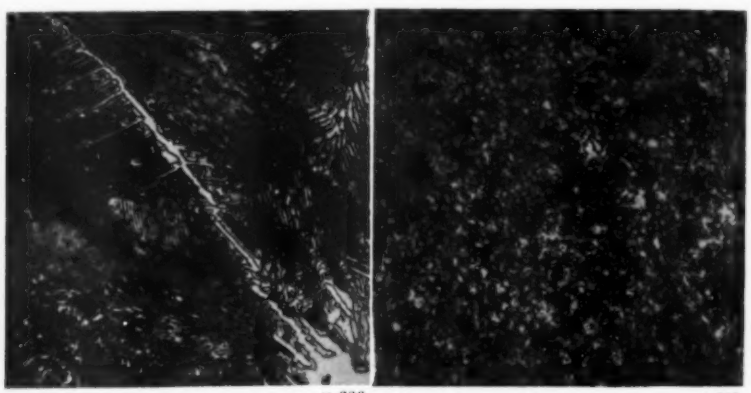
By courtesy of The Ford Motor Co.

Copper in Cast Steels

Copper in amounts up to about 2% is an advantageous addition for many cast steels (Gregg and Daniloff pp. 172–186), as it results in an improvement of mechanical properties, especially with regard to yield point and impact values, while there are also possibilities of modification of properties by thermal treatment. Moreover, there is an increase of fluidity of the molten metal, and this facilitates the casting operations. Experience with cast steels containing copper has been related by both Armstrong[13] and Finlayson[14] and the latter, who has had extensive experience of such castings, finds that tensile strengths of over 40 tons per sq. in. with a yield point of over 35 tons per sq. in. and an elongation of 25% on 2 ins. are readily obtainable upon castings annealed at 900° C. Although there is need for further experimental work it would seem that the cast copper steels are of potential importance, and commercial success has already been obtained within the following compositional range:—

carbon, 0·1% upwards; silicon, 0·3%–1·4%
manganese, 0·6%–1·5%; copper, 1·0%–2·5%.

Automobile Crankshafts, as illustrated in Fig. 1, are cast by the Ford Motor Company[15] from a type of high-carbon copper-steel of composition given in the first column of Table I. This is a revolutionary development in reducing the production cost of crankshafts, and the resulting product has given very satisfactory service results. The fatigue properties of the metal are thought to be enhanced by its high-damping factor. The heat-treatment involves heating to 900° C., air cooling to 650° C., reheating to 800° C., and finally furnace cooling to 540° C., and takes advantage of the change of solid solubility of copper in iron.



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Micrograph of crankshaft metal as cast. *Micrograph of crankshaft metal after heat-treatment.*

SLIGHTLY REDUCED ON REPRODUCTION.

Copper in Cast Irons

In general, copper has a graphitising effect upon cast irons, so that copper additions result in graphitisation and at the same time there is an improvement of mechanical properties. More latitude may be taken in foundry practice, both with regard to composition of the basis irons and also concerning the casting conditions, as the fluidity of the metal is improved and there is less tendency to chill in thin sections.

In the case of malleable irons the addition of copper permits the use of a wider range of basis irons and ensures more rapid graphitisation upon annealing or alternatively permits the use of lower temperatures. Lorig and Smith[16] and Smith and Palmer[17] have studied this influence of copper upon malleable iron and have also found that the alloys are of a precipitation-hardening type. The addition of copper to malleable irons is now being commercially undertaken in this country with a view to shortening the annealing cycle.

In the case of grey cast irons there is much evidence that copper results in an all-round improvement of properties, and automobile cylinder block castings are in certain instances now being made from grey cast iron containing about 0·7% copper; the composition of the cast iron at present being used by the Ford Motor Company[18] for the production of cylinder blocks is given in the second column of Table I. Amongst advantages which are associated with the copper addition are increased fluidity, better anti-fatigue or shock-resistant properties and greater wear-resistance.

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12 *Mining and Metallurgy*, 1935, 16, 464.
13 T. N. Armstrong, *Trans. Amer. Soc. Metals*, 1935, 23, 286.
14 A. Finlayson, discussion of above, p. 313.
15 E. F. Cone, *Metals and Alloys*, 1935, 6, 259.
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(*Continued on page* 46.)

Research and Technical Development in the Tin Industry

By a Special Contributor

Recent research has increased our fundamental knowledge of tin, its alloys, and compounds, which has increased their application in many fields. In this article the author reviews briefly some practical achievements which have resulted, with special reference to researches.

IT is now realised that only by continuous fundamental scientific research and technical development can any product hope to maintain fully its established markets or win new ones.

Among the older industrial metals tin has occupied until recently a position of neglect from the research viewpoint. The lack of fundamental knowledge of tin, its alloys, and compounds has tended to encourage the substitution of tin by other metals in many fields of application. With the object of remedying this deficiency of knowledge, thus securing improvements in products containing tin and in the processes connected with them, and leading to new applications of tin, the International Tin Research and Development Council was formed in 1932 by the Governments of the chief tin-producing countries. The researches of the Council are described in numerous published papers.

The present article gives a brief account of practical achievements with special reference to these and other researches. This progress has been helped considerably by advances relating to other important metals, such as steel, copper and lead, in association with which tin is used.

Tin Coatings

The main use of tin continues to be in the form of a coating on other metals or alloys, chiefly steel, copper, and cast iron, especially in the food industries, where the clean, bright surface of tin, its relative freedom from corrosion, its non-toxicity, and ease of application or renewal are outstanding advantages.

Tinplate. At the present time tinplate accounts for nearly one half of the world's annual consumption of tin, and the chief consumer of tinplate is the canning industry. But the canning industry has encountered a variety of corrosion problems involving, among other factors, the electrochemical relations of the tin coating and basis steel. In the light of recent research these problems are becoming more and more completely understood, and the investigations already carried out have been of benefit to the canning industry in indicating the best conditions for packing different products. Improvements in lacquers and the methods of their application to the tinplate surface have also won far-reaching results in the successful packing of many new food products. A special case is the canning of beer, which during recent months has made great strides in U.S.A. One American can-making firm is now producing tinplate beer containers at the rate of 50,000,000 per month. This new departure, therefore, bids fair to become very important consumer of tin. Canned beer has the advantages over bottled beer of lighter weight, freedom from breakage, easier pasteurisation, and elimination of returned empties.

Advances in the manufacture of tinplate cans and boxes demand high standards of ductility and other mechanical properties, both in the steel and the tin coating. Considerable progress has been made in these directions, not only in rolling practice to render steel sheets of greater ductility and more uniform gauge, but in the understanding of the nature of the bond between the tin and the steel. Increased knowledge of the properties and conditions of formation of the brittle layer of tin-iron compound that forms at the junction of the two metals is throwing light on the conditions required for de-formation without cracking the coating.

Methods for evaluating the porosity of tin coatings on steel and other basis metals have been worked out and are now in constant use in many industrial laboratories. A method for reducing or eliminating the porosity has been devised, which consists of applying a thin electro-deposit of tin over the hot-dipped tin coating. This is of particular importance for fabricated articles. There have been advances in the technique of nickel-plating tinplate, with or without a chromium finish, which is finding extended uses in numerous fancy and utilitarian articles.

Other tin coatings. Tinned steel and tinned copper are largely used for the construction of plant and equipment for the dairy and other industries. Difficulty has for long been encountered in the removal of the tin coating, leading to the exposure of the underlying metal. It has been found that this deterioration is due largely to the attack of tin by the strongly alkaline agents commonly used in the periodic cleaning of such vessels. A new detergent, which has unimpaired cleansing action, but does not attack the tin, has been devised, and is now finding application in the industry. Advances have also been made in the study of the conditions of tinning copper. This outlet for tin has a renewed prospect of being maintained in face of the competition of alternative materials.

Electro-deposition. Advances have been made in the field of electro-deposition. Whilst in the past it has been difficult to built up more than a thin coating of tin by this method, there is now available a process by which an electro-deposit of tin of any desired thickness is readily obtained. The sodium stannate bath used is also characterised by a high throwing power and is applicable to the coating of the inside of tubes. An electro-deposit of tin is now applied to cast-iron pistons for automobiles to assist the "running-in" process. The technique of applying coatings of hardened tin by simultaneous electro-deposition of another metal, such a nickel, with tin has been worked out and should lead to industrial applications. A process has been devised, whereby it is possible to apply non-porous electro-deposits of bronze to steel or other basis metals. Such coatings form an excellent base for a chromium finish and are likely to find a wide range of applications.

Bearing Metals

A coating of a high-tin alloy, containing small amounts of antimony and copper, has long been used as an anti-friction lining on steel or bronze for bearings. The progressive development in design of the internal-combustion engine has made the conditions of service of bearings in such engines more and more severe. Much work is in progress leading to the improvement of tin-base bearing metals to enable them to withstand the more severe conditions imposed. It has been found that the addition of a small amount of cadmium effects an improvement in Brinell hardness, tensile and compressive strengths, and fatigue range. Alloys of this type are now undergoing service tests in different types of engines. The adhesion of the antifriction metal to the backing metal has also been the subject of study, with a view to overcoming failures arising from weakness of the bond.

Tin Alloys

Bronzes. In the bronzes, progress has been made in overcoming the porosity that detracts from the value of the cast material. A recent U.S.A. patent describes the treatment of straight tin bronzes, containing about 6–12% of tin, at temperatures between 500° and 650° C., whereby the structure of the alloy is converted almost completely into the phase, thus effecting a great improvement in the working properties of the bronze. Some work has been done on the properties of special bronzes, made by the addition of other elements. This work and its further development may also be expected to lead to new applications in the future.

Solders. With the increasing use of electricity for domestic purposes the use of tin-lead solders is expanding. Refrigerators and air-conditioning equipment are becoming modern necessities that are leading to an increased consumption of solder. Another new outlet is the replacement of iron pipes for water supplies by copper pipes which have sweated-soldered joints and fittings. The continually increasing requirements have emphasised the lack of fundamental knowledge of the properties of these alloys, particularly regarding creep and fatigue, and the effect of small amounts of impurities. These properties are now being investigated.

Pewter. Pewter, a high-tin alloy, is coming into favour more and more for household articles and ornaments. This revival is due in considerable measure to the greater attention that is now paid to the production of articles of artistic design, to which pewter readily lends itself.

Other alloys. Fundamental work on the constitution of new alloy systems and the re-examination of some of the older systems has led to the production of new alloys or alloys with improved properties, for which it may be confidently expected that applications will arise. These researches have already indicated that the mechanical properties of certain tin-base alloys may be improved by heat-treatment.

Solid Tin

In its solid form tin is maintaining its use in the form of pipe in the food and fine chemical industries. Tin foil remains the most suitable material for the wrapping of cheese. Tin collapsible tubes are used not only for paints, ointments and similar domestic products, but in recent years considerable expansion has occurred, due to their use as containers for numerous food products such as mustard, cheese and fish-paste.

Tin Compounds

An interesting new application of tin, which is already in industrial use, is in the form of tin oleate, which is added to the extent of 0·1% to lubricating oil for motor-cars as an anti-oxidant. The improved oil has less tendency to form sludge and provides better engine performance, with less frequent need for decarbonising and less cylinder wear.

The Nickel Industry in Northern Ontario

ACCORDING to the Sudbury (Ontario) correspondent of the *Financial Post* (Toronto), the nickel companies operating in northern Ontario are still spending many millions of dollars in preparations to supply the world market for many years to come. While present needs are being met with existing facilities and no immediate production increases are contemplated, plans are being made in order that metal stocks may be kept sufficient to supply growing industrial requirements.

Both the International Nickel Co., Ltd., and Falconbridge Nickel Mines, Ltd., are increasing their facilities for ore development. The International Company at the end of this year began the sinking of the new vertical shaft at the Creighton mine, which is now more than half-way down to its objective of 4,250 ft. The shaft is expected to be ready for service by the end of 1936 or early in 1937. It will cost $2,700,000, and its completion will double the hoisting capacity of the Creighton mine. At the present time erection is in progress of the head-frames, power house and other surface buildings. The hoisting installation will be one of the largest in the world, utilising a total of 3,000 h.p. of electrical energy. The shaft will have a capacity of 4,000 tons of ore daily, and the speed of the hoisting equipment will be 2,000 ft. per minute. The cages and skips are being made of nickel-alloy steel, and will carry 60 men at one time. There are six compartments, two of which will be used for hoisting, two for men and material, one for manway and pipeway, one for ventilation.

The Frood mine is hoisting ore at the largest daily rate in its history, and the number of persons employed is the largest ever engaged at the property. Production can be increased at any time, as more than 100 stopes (not all of which are at present worked) have been prepared to deliver ore. At the same time, the Company has the Garson, Murray and Stobie mines in reserve, one or all of which can be placed in operation as and when desired.

Falconbridge Nickel Mines, Ltd., has nearly completed a new shaft on which its main operations will eventually be centred, thus enlarging its entire scheme of mining. It is expected that electrical power from the Abitibi Canyon development will be delivered on November 20, for the service of the new No. 5 shaft, and the new hoists and other machinery are to be ready by about November 25. The transmission line has been completed to join up with the main line near Chelmsford, and a sub-station is now being built on the Falconbridge property adjacent to the new shaft. Substantial progress has been made in operations from the new shaft. On the 500-ft. level drifting eastward in the new workings has reached a distance of about 1,300 ft. in the shaft, virtually all in ore, and recent reports indicated a 15-ft. width of ore on the east face. On the 1,200-ft. level a station capable of large tonnage handling has been opened and drifting both east and west has proceeded for about 200 ft. A cross-cut at this horizon, the lowest in the mine, showed 21 ft. of ore, running 1·7% of nickel, the best selection being five feet in width of 2·3% nickel.

Copper content is increasing in the eastern ore horizon, as compared with the ore in the western working. No immediate production increases are planned, and it is expected that a year will elapse before the main operations are transferred from the original No. 1 shaft to the No. 5. Expanding development work will require at least two years. The mine is now producing at the rate of about 11,000,000 lbs. of nickel and 5,300,000 lbs. of copper, whilst the present working force is about 700 men.

The "Achema VIII," exhibition of chemical plant, organised by the Dechema Deutsche Gesellschaft für chemisches Apparatewesen E.V. (German Chemical Plant Association), will be held in Frankfurt a. Main early in September, 1937, together with the 50th General meeting of the Verein Deutscher Chemiker.

Frankfurt a. Main is not only suitable by reason of its geographical and economic position, but also because it was there that the Verein Deutscher Chemiker was founded in 1887.

Town Gas in the Ferrous and Non-Ferrous Metals Industries

Specially Contributed

The value of town gas as an industrial fuel is generally acknowledged, but as a processing agent by atmosphere control its value is being even further proved. The progress achieved in its application is due, in a large measure, to pioneer work done in the Research Department of the Sheffield Gas Company. In this article general furnace practice and the use of town gas in the Sheffield area are discussed ; subsequent articles will deal with special heat-treatment processes.

OF recent years the use of town gas for heating purposes in the metals industries has shown phenomenal development. Never in the history of the steel and non-ferrous metals industries has so much attention had to be given to the control of all factors bearing on the cost of manufactured units, and it is most significant that where those items have been given the careful attention they demand, the choice of fuel for practically all heating purposes has favoured town gas.

It is certainly appreciated by enlightened users of fuel for industrial purposes that there are certain features of a fuel, other than initial cost per therm, which influence the ultimate overall cost of the article being manufactured, and in many instances, the various items adding to the manufacturing costs have a far larger monetary significance than the initial thermal price of the fuel. Practice has proved repeatedly that the old saying of " one therm is as good as another " is a myth. The conditions of obtaining and using any unit of heat has an economic bearing on the cycles of heating and processing in any manufacturing operation, and when town gas is the fuel used, costs due to labour, machining, grinding, pickling and wasted materials are very much reduced, and in some cases some of those items can even be eliminated.

The Sheffield Gas Company has taken a very important part in the development of the use of town gas for the Sheffield metals industries and being one of the pioneers in the industrial uses of gas, has many years of accumulated experience in all types of heating required for the processing of metals. This information is rendered available to Sheffield firms through the Company's Industrial and Research Departments. The Industrial Staff of furnace engineers and fuel experts are in daily contact with the firms in the area, assisting them with their furnace and heating problems, and are in constant demand by both large and small concerns. The main purposes of the furnace engineers are to design furnaces of special requirement to meet the peculiar local demands and to convert where possible existing solid-fuel furnaces to use town gas at a minimum capital outlay and yet be of high thermal efficiency. Some of the most efficient furnaces in the area are furnaces converted from either solid fuel or producer gas-firing systems.

The Industrial Department is supported by a Research Department, staffed by men of experience in fuel technology, chemistry and metallurgy. This department is of great assistance to the smaller firms in the area who cannot justify the expense of maintaining technical staffs of their own. Their problems of heating, processing, etc., can be brought to the Research Department, and examined systematically, and their products can be examined and tested by the excellent equipment installed for the purpose. In addition to this, the Research Department is actively engaged in direct research in the uses of town gas for local trades, improvements sought in existing methods of combustion, and new uses for gas investigated.

It is pointed out that the services of the expert staffs of the Industrial and Research Departments are offered free of charge to any firm in the area whether they be gas consumers or not.

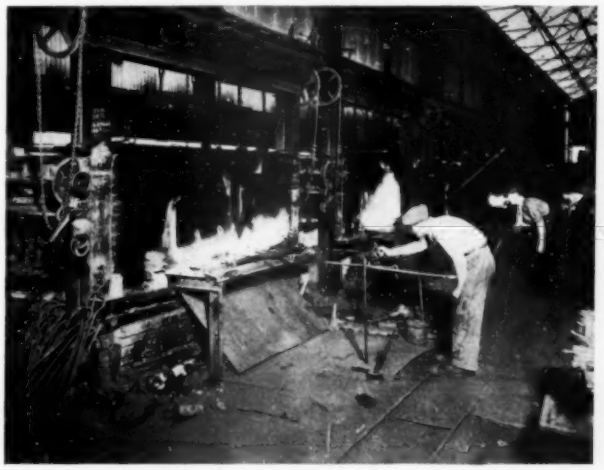


Fig.1.—View of part of a battery of sixteen gas furnaces installed in one works for all types of forging and drop-stamping.

These activities, along with the policy of making available large quantities of coke-oven gas at initial prices which are competitive with other fuels even on a thermal basis have resulted in a demand for gas in the area never previously realised in the industry. To-day, more than 60% of the total output of gas by the Sheffield Gas Company is used in the local metal industries.

Accounts of some of the heating processes carried out in gas-fired furnaces, followed by the descriptions of the more recent developments in the use of gas for high-speed steel hardening, nickel silver and stirling silverbright annealing, will indicate the value of town gas not merely as a fuel supplying heat, but as an agent definitely, eliminating other costly processes and ensuring high-quality production.

GENERAL HEATING PROCESSES CARRIED OUT IN GAS-FIRED FURNACES

(i) Billet-Heating for Forging and Drop-Stamping

Furnaces for the heating of billets for forging and drop stamping are seldom of a continuous type. They are usually " in and out " furnaces, largely because of the fact that a great variety of shapes and size of articles are dealt with. Such furnaces require to be as efficient as possible, and capable of rapid temperature changes when desired. For repeat work, where they can be run continuously for long periods, use of recuperation is a big advantage and furnaces designed to this end are in everyday use, mostly with brick recuperators, and separate gas and air ports. Rapid heat transfer from the luminous flame obtained results, and the rate of heating for forging is not limited by metallurgical requirements.

Heating for forging may be done as rapidly as is consistent with good hammer operation. But here again too great a flame temperature causes serious damage to steel, since it is at forging temperatures that scaling and decarburisation of steel become very pronounced. The

Fig. 2.—Front view of part of a battery of sheet-heating furnaces. The furnaces are the hand-operated regenerative type, and the combustion can be so controlled as to give the necessary atmosphere control for the proper type of "finish" on sheets of varying kinds of steel.

temperature is so near the fusion point of scale, that lack of temperature control often results in burning of steel. In passing, it may be mentioned that it is the very high-flame temperature produced by oil that mitigates against its successful use for this purpose. In forging, therefore, flame contact should be avoided. The furnace temperature should be so controlled that at no time and in no place in the furnace will the burning temperatures of the steel be exceeded, since the detection of forgings damaged by burning is very difficult if the fault fails to show at the surface. The operation of forging furnaces with an excess of gas, producing a somewhat reducing atmosphere, will tend to prevent burning.

TABLES I. AND II.

The results shown in these tables indicate the excellent performance to be obtained from modern gas-fired furnaces for heating steel for drop-stamping. The tests were made on two different designs of furnace, one proving to be more efficient in this case than the other.

No. 1 Test on Regenerative Furnace for Drop-stapming Cranks.

Time.	Gas Rate per Hour.	Output of Cranks, 71 lb. Each.
1	2	3
7.30 a.m.	Start	—
8.30 „	2,400	10
9.30 „	2,700	19
10.30 „	2,500	20
11.30 „ to	2,600	18
12.0 noon	—	5
1.0 p.m. to	—	—
1.30 „	2,600	7
2.30 „	2,300	14
3.30 „	2,500	19
4.30 „	2,500	23
9.0 „	3,400	—
9.30 „	3,200	6
10.0 „	3,400	10
10.30 „	2,900	8
11.0 „	2,700	12
11.30 „	2,700	—
12.0 midnight	2,580	23
Average rate per hour lit from 7.30 a.m. to 12.0 midnight	2,635	Total 194

Consumption of Gas per Lb. of Output.

7.30 a.m.—12.0 noon	2·01 cub. ft.
1.0 p.m.— 5.0 p.m.	1·92 „
9.0 p.m.—12.0 midnight	2·09 „
Per hour worked	2·01 „
Per hour lit	2·20 „

Total Gas Consumption and Output.

30,340 cub. ft. ..... 13,774 lb. steel

Temperatures.		*Thermal Efficiency.*
Maximum	1,345° C.	
Minimum	1,230° C.	33·7%
Average	1,297° C.	

No. 2 Test on Regenerative Furnace for Drop-stamping Cranks.

Time.	Gas Rate per Hour.	Output of Cranks 71 lb. Each.
1	2	3
7.30 a.m.	Start	—
8.30 „	1,800	15
9.30 „	1,800	23
10.30 „	2,070	19
11.30 „ to	2,280	17
12.0 noon	—	2
1.0 p.m. to	—	—
1.30 „	2,260	6
2.30 „	2,150	20
3.30 „	2,390	20
4.30 „	2,100	24
9.0 „	2,200	—
9.30 „	2,520	1
10.0 „	2,280	11
10.30 „	2,180	11
11.0 „	2,220	9
11.30 „	2,560	—
12.0 midnight	2,240	27
Average rate per hour lit from 7.30 a.m. to 12.0 midnight	2,197	Total 205

Consumption of Gas per Lb. of Output.

7.30 a.m.—12.0 noon	1·47 cub. ft.
1.0 p.m.— 5.0 p.m.	1·56 „
9.0 p.m.—12.0 midnight	1·67 „
Per hour worked	1·56 „
Per hour lit	1·69 „

Total Gas Consumption and Output.

24,540 cub. ft. ..... 14,555 lb. steel

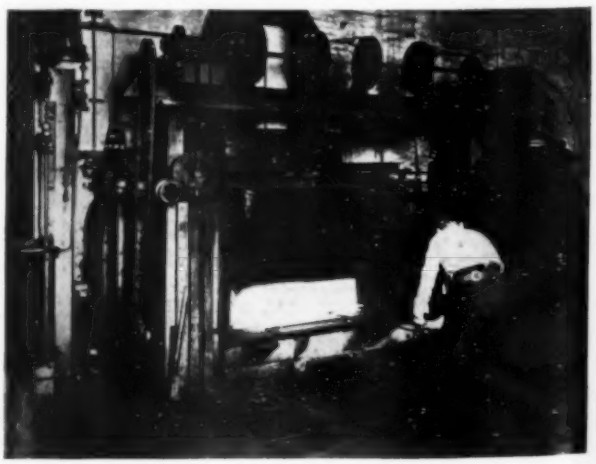
Temperatures.		*Thermal Efficiency.*
Maximum	1,360° C.	
Minimum	1,275° C.	43·8%
Average	1,306° C.	

Satisfactory as gas-fired forging furnaces have proved to be, considerable improvements have been made in the last few years, notably in the prevention of surface damage to steel. Small furnaces even for "jobbing" work are being developed incorporating the diffusion-flame principle and the use of recuperators, to allow the same successful heating for the forging of small articles of steel as for large forging and drop-stamping.

For the heating of steel for drop-stamping, some of the finest furnace equipment, using town gas, is available and is used to-day.

Such furnaces usually embody brick regenerator systems or heat-storage equipment, the alternative heating up of the chequer work by flue-gases and absorption of stored heat by air for combustion usually being done at stated

Fig. 3.—A recuperative gas furnace for the heating of billets and slabs for rolling into sheets. The furnace is also used for sheet normalising.



intervals. Simple manual reversal, or mechanically operated reversing apparatus can be employed. The salvage of the heat in the waste gases by standard furnaces designed on these lines gives excellent operating efficiencies on long-period working. Here again the highly radiant type of flame, so arranged as not to come in direct contact with the steel being heated assists in giving rapid heat transference.

(ii) Sheet Heating

Sheet heating is one of the old processes for which it was deemed essential to have black smoke in the heating chamber. The reasons given for the presence of smoke or carbon particles have been various, but the object at any rate was primarily to preserve what is termed the "finish" of the sheet. When a sheet is rolled to a particular gauge, it is covered with a very adherent form of scale-rolling scale. This is very thin, and blue-black in appearance, and it is desirable to preserve this appearance after normalising to remove rolling strains. The temperature used for normalising such sheets is low, but sufficiently high for further oxidation by free air to take place, so it is a necessity rather than a virtue, that black smoke be present when using solid fuel, when maintaining such a low temperature. The carbon particles further assisted in preventing the "sticking" of sheets when put in the furnace in piles.

Town gas-fired sheet furnaces are in common use to-day, and the sheets have lost nothing of their earlier desirable "finish." In fact, this class of furnace can now be used for certain special steel sheets demanding even closer control of temperature and furnace atmosphere. These furnaces are built on very similar lines to those described for heating for drop-stamping incorporating a similar regenerator system, but usually having a larger working hearth. The method of combustion, separate gas and preheated air, is slightly different. Very incomplete combustion occurs at first, giving a large excess of gas in the working chamber, which decomposes to give rise to smoke—carbon particles—and reducing gases. This atmosphere is similar to that occurring in a coal-fired furnace for the same purpose, but the amount of free air is appreciably less. These products containing excess gas are further admixed with air, outside the working chamber, the heat thus derived being available for heating the hearth of the furnace, or of increasing the temperatures of the regenerator brick - work, and hence the air for combustion. The efficiency of such furnaces, from a thermal standpoint, is naturally not so high as in drop-stamp furnaces, but from a process point of view they are admirable.

(iii) Annealing

With annealing furnaces again, the bogey of black smoke from solid fuel-fired furnaces has persisted for years. The annealing of steels is a particularly important process, since the bulk of the steel supplied to tool manufacturers is the starting point of many intricate tools. Reference to certain metallurgical items is unavoidable, if a proper understanding of the difficulties of annealing is to be realised. The annealing temperature of ordinary steels is sufficiently high for damage to the surface of the metal to occur if oxidising gases are present. This damage is two-fold, scaling of the steel and removal of the carbon in the surface of the steel occurring simultaneously. This latter feature—decarburisation—is more undesirable than is simple scale, and unfortunately, when steps are taken in solid fuel open-type furnaces to prevent scaling, the amount of decarburisation usually increases. Consequently box annealing, or close annealing, has had to be used, the material to be heated being packed in metal containers along with some material such as charcoal to prevent damage by free oxidising gases. Since the introduction of gas-fired annealing furnaces, many of these difficulties have been removed. Standard types of open-gas-fired furnaces are in daily use, where there is no need to pack the steel in expensive containers, and where the products of combustion containing no free air allow good commercial results to be obtained at competitive costs.

Fig. 4.—Another sheet-heating furnace similar to those shown in Fig. 2. The gas-burning equipment can be seen on the left of the furnace.

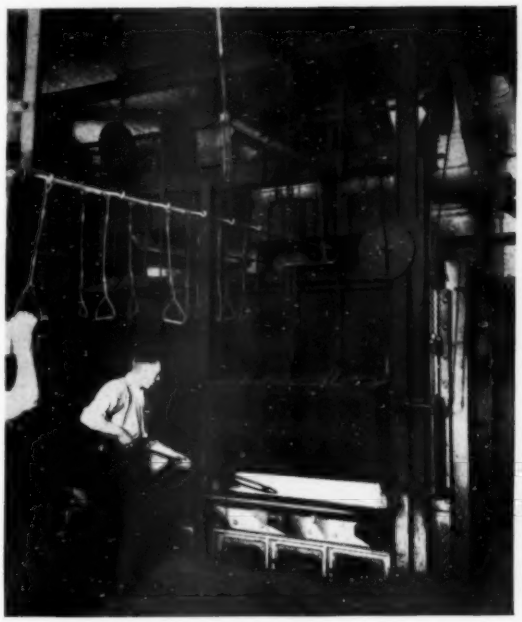


Fig. 5.—A further type of sheet-heating furnace, of the recuperative type, similar to the one shown in Fig. 3.

(iv) Heat-Treatment for Hardening

It is in this field of the application of heat that we have the most varied and difficult conditions with which to contend. In this, one of the final stages of the heating of steels, the greatest care requires to be taken, since the steel has received the major part of its machining or mechanical treatment into its final form, any surface damage requires to be removed by grinding, machining, sand-blasting or pickling, according to the form of the article and these operations represent expensive labour, time, apparatus and material. It is here that the factor of temperature control probably demands the closest attention, since it is this which primarily controls the ultimate service value of a steel article. Exact temperature control is very difficult with solid fuel fired furnaces, and the use of coke hearths for the dual purpose of forging and hardening is much to be deprecated, and is fortunately rapidly disappearing. It is the skill acquired by experience which enables a satisfactory article to be obtained in solid fuel furnaces, and the ability to judge temperatures by eye is being replaced by the use of standard instruments in

conjunction with furnaces fired by town gas under properly controlled conditions of combustion.

The temperature of a gas-fired furnace is capable of very ready control by the hand adjustment of the burners, and in addition the types of mixing apparatus and burners available to-day make automatic temperature control a simple and successful proposition. Automatic temperature control apparatus used in conjunction with modern gas-burning apparatus allows of a degree of temperature control not surpassed by any other method of industrial heating.

There are many types of gas-fired heat-treatment furnaces, ranging from single small units such as oven-furnaces and muffles, to large continuous furnaces for mas-production purposes. Every type of combustion of town gas is used, depending upon the temperature and distribution of heat required. Natural draught, gas and air under low pressure, gas and air at high pressure, and high-pressure gas, are used in many types of industrial burners. Most have for their object maximum burner efficiency coupled with furnace designs to give maximum furnace efficiency. There is little purpose in describing the common forms of heat-treatment furnace, but one or two special process furnaces may be mentioned with advantage, since they have taken no small part in developing the fabrication of certain forms of steel, and of developing mass-production systems.

(v) The Continuous Furnace

The ability to maintain an even or uniformly graded temperature in a long-heating chamber has enabled mechanical production for heat-treatment of steel articles to be carried out on particularly economical mass-production lines. The use of heat-resisting belt or chain conveyers suitably designed to hold particular shapes of tools to be treated, passing through the furnace at suitable rates to allow the proper temperature to be reached, and maintained for the necessary period makes possible the production of uniform articles continuously. As the conveyer leaves the furnace, the heated articles fall off into a suitable quenching medium, usually oil, water or brine, often without coming into contact with air. The type of atmosphere in the heating chamber can be varied over wide limits, according to the type of steel and temperature required for its hardening, and the tools consequently require the minimum amount of subsequent work to render their "finish" suitable for marketing.

In certain instances, such as safety-razor blade or small diameter wire manufacture, the use of a refractory or heat-resisting steel muffle purged with raw gas gives excellent commercial results. The low temperature used, the short heating period, and the effect of the raw gas purge, results in a perfectly bright article, requiring no subsequent cleaning. Over 90% of the safety-razor-blade manufacture is done in such gas-fired continuous furnaces.

For the many heat-treatment processes required in the manufacture of steel wire, such as annealing, normalizing, lownealing, highnealing, pearlitizing, "Patenting," etc., gas-fired continuous tube or open type furnaces lend themselves admirably, principally because of the accurate control and grading of temperature possible.

Continuous furnaces for steel strip of special alloy steels such as stainless steels are widely adopted for similar reasons, and because they lend themselves admirably to the other essential features such as atmosphere control, continuous de-greasing, quenching, and where necessary simple or electrolytic pickling.

The more recent adaptations of gas-fired furnaces for these special steels and special forms of steel will be detailed in the final section.

(vi) Tool Heat-Treatment Furnaces

It is in this field that the varied methods of adaptation of town gas to the production of controlled heat are most widely used. The variety of tools manufactured to-day, is such that the design of the furnaces is primarily controlled by the shape of the tool itself, and by the rate of production required. The necessity of hardening only part of a tool, say the edge in the case of machine knives and scythes, the cutting part of a twist drill, reamer, or hob, and not the shank, the face of a die and not the back, the teeth in flexible backed hacksaws, and the blade of a knife and not the bolster, makes demand upon furnace construction and design which necessitate very careful systems of heating. These difficulties, coupled with the necessity of attention to temperature and atmosphere control, are such that in many cases the flexibility of town gas, makes its use preferable to any other form of fuel. Many furnaces for these purposes are of unique design and do not appear in trade catalogues, but furnace builders show enterprise which is appreciated in meeting special demands.

For many purposes, the use of indirect heating by means of salt-baths and lead baths is admirable. A bath of salts maintained in a state of fusion at the proper temperature by a natural draught burner, or by composite burners, allows great rapidity of heating, and where temperature indicating or controlling apparatus is incorporated, the danger of overheating is eliminated.

In addition, only that part of a tool requiring to be hardened need be immersed. A further important feature is that the danger of surface damage by scaling or excessive decarburisation is avoided, and even when the tool is taken out of the bath, the coating of salts remaining on it, protects it from the action of air before quenching. These baths are widely used for carbon steels in the forms of twist-drills, reamers, taps, milling cutters, files, cutlery and small intricate tools, but their use is confined to processes where the temperature is usually not higher than 850° C. Salt baths of suitable composition are equally successfully used for tempering of steels. Lead baths are used for similar purposes, and are preferred in the case of files and certain forms of heavily cut tools.

Salt baths have been used for high-speed steel tool hardening, but experience has shown that not only is the use of baths at very high temperatures expensive, especially in replacement of pots to hold the salts, but that the temperatures attainable are not sufficiently high for correct heat-treatment purposes.

A further essential for the correct heat treatment of tools is tempering, or "drawing" as it is commonly termed. It is still common practice to give insufficient attention to this metallurgical requirement, but experience has shown conclusively that the use of the proper temperature and time of heating adds materially to the value of the tool. The method of heating to a desired surface colour of the metal, known as colour tempering, is being replaced by methods employing accurately known temperatures. The use of salt baths has already been mentioned, but heated oil baths, temperature controlled oven and muffled furnaces and hot-air furnaces are also used extensively.

The gas-heated air circulation furnace is a comparatively recent development and is proving to be a very successful unit for secondary heat-treatment and for tempering.

With regard to high-speed steel, this use of a further heat-treatment after hardening is particularly important, and it should not be confused with simple tempering.

To be continued.

Oil from Coal

The principal unit of the new oil-from-coal plant recently erected at Seaham Harbour is now in operation. The works were begun less than nine months ago, and have been erected ahead of schedule time. The present plant will deal with 500 tons of coal per day, and will produce about 4,000,000 gallons of motor spirit, 4,000,000 gallons of Diesel oil, 100,000 tons of smokeless fuel, and hundreds of tons of valuable by-products per annum. The directors have already decided on the duplication of the main plant, which virtually means the doubling of the factory. Duplication will begin shortly, and will give employment to a large number of extra hands.

Recent Trends in British Iron and Steel Production

By K. R. BINKS

THE production of steel ingots during the current year might once again in the history of the last twenty-five years be said to approach that of prosperity levels. Indeed, should the monthly average of the first three-quarters of this year be maintained for the whole twelvemonth, 1935 will rank with the peak years of 1917 and 1929. Table I. gives the comparative outputs, that for 1935 being calculated on a nine-months' period.

TABLE I.

Year.	Average Output per Month.
1917	809,712 tons
1929	804,600 ,,
1935	802,255 ,,

It thus appears that the present activity in the steel industry parallels that of the busy war years and of the period following on the suspension of production in the industrial disturbance of 1926. Both these latter periods may be said to have been abnormal when considered from the standpoint of real prosperity, for in the one there was heavy destruction of steel products in war material, and in the other a definite shortage of supply to steel consumers created by prolonged closing down of works. Such improvement in steel output to present levels is therefore all the more remarkable since it is the result of steady growth. Fig. 1 shows in graphical form the progressive rise in the tonnage of iron and steel produced in Great Britain from the year 1932 onwards. The causes leading to such expansion in output could not perhaps be called abnormal, but were closely allied to a general increase in national prosperity, protection of the home markets from outside influences, and a rational policy for the regulation of the steel industry as a whole.

What relation to steel ingot capacity does this present output bear? It is noteworthy that practically the whole of British steel ingots in the heavy industry are produced by the open-hearth process, either in the basic or acid furnace, and a calculation of the output capabilities under the technical conditions realised in this country gives a hypothetical figure of about eleven million tons. Assuming therefore the maintenance of the present rate of monthly production, it appears that current output is realised from approximately 87% of the total potential capacity of the furnace plants. Repair periods, week-end stoppages, and other unavoidable interruptions in the productive life of the furnace will account for the major part of the balance of 13% shown as unproductive, and under these conditions great expansion of the present output of open-hearth steel might not be within sight.

Price

How has the price realised by the industry for its products moved during this period of activity and re-organisation? Table II. shows the basis price in the home markets for certain steel products during past years, in comparison with that for September of the present year.

TABLE II.

Product.	1930.	1931.	1932.	1933.	1934.	Sept.
Soft steel billets	122/9	106/3	105/6	106/5	110/–	110/–
Sheet bars	118/4	97/4	95/–	96/3	103/1	107/6
Ship plates ...	175/–	175/–	175/–	175/–	175/–	175/–
Joists	170/–	175/–	175/–	175/–	175/–	175/–

Since 1932 it is apparent that the base price of ship plates and joists (which are further subject to the operation of a rebate scheme to home consumers) has remained stationary, while that of soft billets and sheet bars has moved up, the latter, however, being still considerably below the ruling price for the year 1930.

Turning now to the raw materials required in large quantity by the iron and steel industry, Table III. shows the increase in price of blast-furnace coke and steel melting scrap since 1932.

TABLE III.

—	1932.	1933.	1934.	1935.
Blast furnace coke	16/0¼	16/1¾	20/–	19/–
Heavy scrap.....	35/–	38/4	51/4¼	52/6

A comparison of Tables II. and III. will show that the increased cost of raw materials has not been wholly passed on to the consumer of steel works products, to whom, indeed, the price has been less than that ruling for 1930, but has been absorbed by the steel producer. It is interesting to note, therefore, that in addition to high production figures for this period, technical efficiency also has been sufficiently advanced to counteract increased price of certain raw materials.

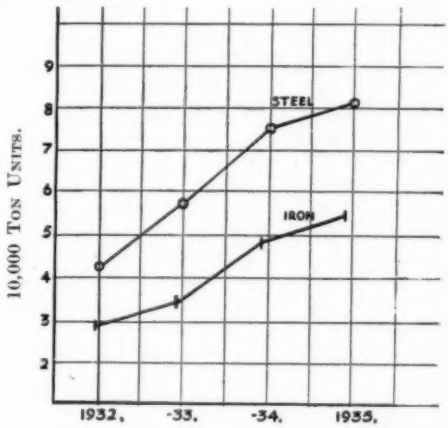


Fig. 1.—Monthly averages of iron and steel production.

Perhaps a concrete illustration of the recent improvement in the iron and steel industry is afforded by the increased marketable value of the equity in the assets of producing companies as shown by the following comparison: Taking the nominal value of the ordinary share capital in the more prominent companies at a figure of 100%, this value stood in October, 1934, at a figure of 86·4%, but by October, 1935, had reached 141·3%, reflecting improvement to a considerable extent in the prospects of the industry.

Imported Material

The amount of material imported into this country from foreign sources has, of course, a major effect on the operations of British steelworks. Reference to Table IV. gives the total monthly averages for all kinds of steel imported and exported since the year 1932, expressed in 1,000-ton units.

TABLE IV.

	Imports.		Exports.
1932	132·7	..	157·4
1933	81·0	..	160·0
1934	113·9	..	187·8
1935 (8 months)	96·5	..	194·7

These figures show a reduction in the quantity of imported material for 1935 from that of the monthly average for the year 1934, but not quite to the lower level attained in 1933. On the other hand, reference to the column of average monthly exports of iron and steel material from this country will show a steady increase in quantity since the year 1932. This position therefore might be considered to have developed along satisfactory lines during the current year.

It might be of interest to express in greater detail the principal quantities of semi-manufactured steel making up the imports. Table V. shows these in comparison with the monthly average for the year 1934.

TABLE V.

Imported Material.	1934 Average. Tons.		1935 September. Tons.
Billets, blooms	27,563	..	21,965
Wire rods	7,080	..	5,801
Sheet bars	9,696	..	7,001
Bars, angles	23,405	..	16,785
Girders (joists)	8,363	..	8,675

These products, representing in part the raw material for the re-rolling industry, amount to some 60% of the total imports, and form a quality and type of section which may be a valuable outlet for the expansion of the home-produced outputs.

Technical Developments

During the current year many announcements of the comprehensive technical re-organisation in progress have been made by producers of iron and steel. Noteworthy among these are the completion of a composite Works employing the basic Bessemer process, development of the acid Bessemer process, the erection of new open-hearth steelworks on the most modern lines, re-building and enlargement of blast-furnaces and existing open-hearth furnaces, and re-equipment of rolling mill installations on the most modern principles.

Reviews of Current Literature

General Foundry Practice

THE preparation of a reliable book on foundry practice is probably more difficult than on any other subject. This is no doubt due to the fact that though the fundamental principles involved are recognised their application is varied considerably in different districts. Further foundry practice has become sectionalised and each section is regarded, rightly we think, as the work of a specialist, upon which a book could be entirely devoted. Under the circumstances, very wide experience and considerable knowledge is necessary to be able to convey useful information on each section without emphasising any one unduly. There is a natural tendency to stress a particular section with which an author has obviously had more experience. This is evident on perusing the majority of books which have been written on foundry practice. Just consider for a moment what is embraced by general foundry practice, then the difficulties encountered by an author will probably be appreciated. Broadly speaking, moulds are prepared in green sand, dry sand and loam, while die casting is now an important section of founding. Each is a type requiring special skill and almost invariably the moulder is confined to one particular type of metal; thus the moulds for steel, iron, brass and bronze, aluminium and magnesium castings conform to principles suitable for the particular metal to be cast and have become specialised operations. The different metals and alloys used necessitate many variations in practice, while the difference in the size of castings, and the number of particular kinds, make differences in the types of moulds used. Without considering metal mixing and melting the comprehensive character of general foundry practice will be recognised. With this in mind, the writer has no hesitation in regarding this book by the late Dr. Andrew McWilliam and Dr. Percy Longmuir, as one of the most practical books on foundry practice.

Originally published in 1907 the book was written to give a condensed and lucid account of the science and practice of iron, steel and brass founding to provide the greatest benefit to all connected with the production of castings. The authors drew from their combined experience gained under normal foundry conditions and under the conditions of experimental laboratories and works, and at that time they stated that practically every operation described had been personally followed, so that the description reflected the experience of actual workers and not merely spectators. Since its initial publication this work has been recognised as an authoritative treatise and additional editions have been necessary.

Recently the fourth edition was published. It has been revised throughout and enlarged by Dr. Percy Longmuir. The present edition, while prepared in conformity with its predecessors, reflects the actual experience of current foundry practice and in the writer's opinion remains one of the most informative books on foundry practice published The book is primarily intended for foundry managers and foremen, but all intelligent foundrymen would obtain benefit from it, while apprentices who are studying the intricacies of foundry practice with a view to progress in the science and practice of iron, steel and brass founding will find this book of the utmost value. Even the engineer, designer and student of metallurgy should benefit from a careful perusal of the text, particularly the latter because, in many respects, it successfully bridges the gap between science and practice.

While maintaining a very high opinion regarding the value of this book there are two important aspects of foundry practice—*viz.*, cleaning and welding, it is thought, should be included, in a comprehensive study of this kind. When castings are extracted from their moulds the work of the foundry is not finished, the castings must be made presentable and ready for dispatch, and the inclusion of reliable information at this end of production would tend to make the book more complete, however, there is no hesitation in recommending it as a thoughtful and valuable book on foundry practice.

By the late Andrew McWilliam, C.B.E., A.R.S.M., D.Met., and Percy Longmuir, D.Met., M.B.E. Revised and enlarged in this, the fourth, edition by Percy Longmuir D.Met., M.B.E., and published by Charles Griffin and Co. Ltd., 42, Drury Lane, London, W.C. 2. Price, 21s. net

Personal

Mr. George Mills, F.S.S., M.Inst.T., divisional general manager, Scottish Area, L.N.E.R., Edinburgh, has been added to the Commission of the Peace for the County of the City of Edinburgh on the recommendation of Sir W. J. Thompson, late Lord Provost of the City. Mr. Mills in addition to being divisional general manager of the L.N.E.R. is a director of several other companies.

All who employ oil hardening will be interested in the new brochure recently issued by G.W.B. Electric Furnaces, Ltd., Elecfurn Works, North Road, Holloway, London, N. 7, in conjunction with Shell-Mex and B.P., Ltd. Some time ago a booklet was issued on Shell-Wild-Barfield quenching oil, in which were outlined a number of important points which influence the suitability of quenching oils. In this new brochure these problems are considered in fuller detail and more from the technical aspect. Among many points discussed are the effects of oxidation on the stability of oils, the effect of cyanide and other salts on oils, and also information regarding sludging, volatility, thermal conductivity, critical cooling speeds, and viscosity.

The X-Ray Powder Photography of Alloys

X-ray photographs provide the research worker with a means for analysing the structure of materials, particularly those that are difficult of investigation by any other method. Dr. A. J. Bradley, in a recent lecture before the Midland Metallurgical Societies, considered powder photography only, and in this article the salient points in the lecture are presented.

THE microscope, said Dr. Bradley, makes use of visible light, that is, radiation of wave lengths varying from $6{\cdot}5 \times 10^{-5}$ cms. for the extreme red to $4{\cdot}5 \times 10^{-5}$ cms. for the extreme violet. By using a photographic plate instead of the human eye, radiation of shorter wave length may be employed, but there is a limit to the process. It is true that far shorter wave lengths exist and are easily produced from an X-ray tube, and these can be registered on a photographic plate, but they cannot be focussed by any lens system so far invented. Hence, it is not possible to perceive objects which are smaller than a certain limit of size, either by direct vision or by means of microphotography. There is, therefore, no possibility of seeing an atom. It was, however, pointed out by Professor von Laue in 1912, that the typical X-ray wave lengths are of the same order of magnitude as the atomic dimensions, that is, 10^{-8} cms. In subsequent investigations Sir William and Professor Bragg used this fact in order to prove that atoms are regularly arranged in a three-dimensional network. The essential principle of their discoveries and of all following investigations of the structure of crystalline solids lies in the use of the X-ray tube as a supermicroscope. Although the atoms cannot be seen individually, they can be made to give patterns on a photographic plate characteristic of the atomic arrangement as a whole. The art of photographic X-ray analysis consists of obtaining and interpreting these patterns, which are as characteristic as finger prints. X-ray powder photographs in many cases allow distinctions to be made with more certainty than by microphotography. Of course, considerable experience is required for the interpretation of results, and above all the X-ray investigator has the invaluable advantage of the data gathered together by many years of successful investigation by the microscopic method. Making full use of this data he is nevertheless astonished by the greater penetrating power of the X-ray technique in difficult cases which have not been fully investigated by other methods.

The most fundamental problem is to establish the equilibrium diagrams of the alloy systems. Since there are 92 elements, the bulk of which are metallic, the number of possible binary systems is immense. Many even of the commonest are still incompletely investigated by the standard metallurgical methods. X-rays can do much to help on this work, and possibly they will provide the most satisfactory methods for the solution of all problems involving phase equilibria.

The phase diagram of the silver-cadmium system, which may be taken as an example of a typical binary system, has been fully investigated by thermal and microscopic methods. The liquidis line, which varies between 323° C. for pure cadmium and 962° C. for pure silver marks the boundary between a liquid state and the solid alloys. The latter may exist in six different states. Each of these states or phases is distinguished from the others and from the liquid state by the mode of arrangement of the atoms, Each phase, therefore, gives its own type of X-ray pattern, which may easily be recognised on a good X-ray powder photograph. In the thermal equilibrium diagram the six single phase regions are separated from one another and from the liquid state by two-phase areas. An alloy whose composition and temperature fall in one of these regions is found to consist of two kinds of material. For example, an alloy of the alpha and beta region will contain crystals of alpha mixed with crystals of beta. Under the microscope single-phase and two-phase alloys may clearly be distinguished.

In an X-ray investigation of an alloy system the first task is to attempt to obtain photographs characteristic of each phase of the system. The atomic arrangement throughout each crystal follows a regular sequence like the repetition of the pattern on a wallpaper. Just as a two-dimensional pattern may be repeated in either squares, oblongs, triangles or parallelograms, so there is a limited number of ways in which a three-dimensional pattern may be repeated. Thus all crystal structures belong to one of fourteen space-lattices. Of these the three-cubic lattices give the simplest X-ray pictures. Fortunately very many alloys crystallise in the cubic system, so that X-ray diagrams may very often be interpretated by inspection.

Probably the most easily understood X-ray pattern is that given by a powdered cylindrical specimen placed at the axis of a circular camera, the film being wrapped round the circumference. The simplest possible pattern is given by potassium chloride, which produces the lines characteristic of a cubic lattice. They may be recognised by their regular sequence. Each set of atomic planes helps to produce a line, the position of which depends on the interplanar spacing. The pattern of sodium chloride is slightly more complicated because sodium and chlorine atoms are not equal in weight like potassium and chlorine. It is, therefore, more truly typical of a compound. The corresponding lines on the two patterns do not occupy quite the same position. The displacements are caused by the different sizes of the unit cubes of potassium chloride and sodium chloride. The exact size of the unit cube can be found with an accuracy of about one part in fifty thousand.

The method of spacing determination is as follows—the exposed portion of the film is terminated at either end by a knife-edge casting a sharp shadow on the film. When the latter is measured up the whole distance between the two shadows S_k is found at the same time as S the distance between a pair of corresponding lines. Then the reflecting angle θ is related to S by the equation $\frac{\theta}{S} = \frac{\theta_k}{S_k}$ The angle θ_k is a constant for the camera, and is found by means of a calibrating experiment with quartz for which the θ values are accurately known. If the crystal is cubic the θ value found for each pair of lines may be used to calculate the length of the cube edges from the formula :

$$a = \frac{\lambda}{2}\sqrt{\frac{n^2\ k^2\ l^2}{\sin\ \beta}}$$

where λ is the wave length of the X-rays and h kl are the indices of the reflection producing the lines. Owing to the existence of systematic errors the values of a are not quite accurate. It is found that by far the best values are obtained from lines near the ends of the films, where θ is a little less than 90°.

In a recent investigation of nickel-aluminium alloys, Dr. Bradley had examined the variation of the cube dimensions when the proportion of aluminium is varied. In a series of alloys around the composition NiAl there are considerable differences which are shown by the big displacements of the end lines of the patttern.

Lattice spacing measurement give a very accurate means for measuring coefficients of expansion. The alloy may be

heated in the camera during the exposure, and the resulting change in lattice dimensions is found from the displacement of the end lines, on the powder photograph. The linear expansion of the crystal lattice is exactly equal to the linear coefficient of expansion measured by optical means. Jay's measurement of the thermal expansion of quartz made by this means are in perfect agreement with the earlier work of Randle and Muller using optical methods. The X-ray work, however, goes further in giving valuable information regarding the alpha-beta transformation.

In the application of these methods to alloy work, an important point is the choice of a suitable radiation. It is essential that the absorption coefficient of the alloy for the X-rays used should be low. Moreover, accurate spacing measurements require lines reasonably near the ends of the films. For metallic nickel, which is face centered cubic, these conditions are satisfied by X-rays from either a copper or a manganese target, but by no others. Copper radiation is, however, useless for the investigation of alloys consisting chiefly of iron, as the absorption is too great.

To obtain accurate lattice spacings, it is also essential that the end lines on the powder photograph should be clearly resolved doublets. This will usually only be the case if the alloy is subjected to correct heat trreatment. For example, alloys deformed by cold working should be reannealed before the photograph is taken.

In a two-phase alloy, the lattice spacings of the two constituents may be determined independently, for example, the face-centred cubic nickel pattern is retained when aluminium is dissolved in the metal up to about 4% of aluminium by weight. Another aluminium alloy containing about 86·7% of aluminium, corresponding to Ni_3Al is also face-centred cubic, but with a much bigger lattice spacing. Alloys of intermediate compositions give X-ray patterns showing the lines appropriate to both spacings superimposed. Such a superimposition of two patterns is characteristic of a duplex alloy. Thus a two-phase region of a thermal equilibrium diagram can instantly be recognised from the powder photograph provided that the patterns of the pure single-phase regions are known.

A less obvious example of a two-phase region is shown in the alpha and beta region of the copper-aluminium system. The alpha phase is face-centred cubic, the beta phase resembling gamma brass is called agamma structure. The powder photographs in the alpha plus beta region show a gradual change-over from the face-centred cubic pattern to the complicated beta pattern. Finally the pure beta phase is obtained at a composition Cu_9Al_4 and the structure of this alloy is remarkable. It is on the whole like that of Cu_5Zn_8. There are in both regions 52 atoms in the unit cell, which can be regarded as built up by stacking together 27 small body centred cubes in rows of three. Since each body-centred cube is associated with two atoms, centre and corner (the eight corners are shared by eight cubes) the structure should have 54 atoms. In fact, there are only 52. The centre and corner atoms of the big cube are absent, and their places are filled by displacements of the neighbouring atoms. In the grouping of its atoms this structure conforms to the tetrahedral type of cubic symmetry.

In many instances, the X-ray photograph is considerably influenced by heat-treatment. Apart from such mechanical effects as removal of strains and elimination of coring, X-rays give evidence of two main types of change. Either there may be a complete phase change, or the atoms may become more regularly distributed within the same phase. The latter changes cannot be detected microscopically, but have considerable influence on the physical properties, especially the electrical conductivity. The classical researches of Johansson and Linde on the copper-gold alloys are of special interest in this connection.

The problem of atomic distribution occurs again in the iron-aluminium alloys. Up to fifty atomic per cent. of aluminium they all have body-centred cubic lattices, but the distribution of the iron and aluminium atoms among the points of the lattice continually changes both with composition and with heat treatment. With low-aluminium content, the iron and aluminium atoms are distributed at random. There is equal probability of a given atom being iron or aluminium, consequently, the X-ray pattern just shows a body centred-cube. Later extra lines appear on the pattern. The alloy appears to behave to X-rays as if it were either a compound Fe_3Al or FeAl. It differs from a true compound however, since these patterns occur at compositions far removed from the theoretical, without change of phase.

A sequence of four position in the body-centred cubic lattice can be distinguished, called A, B, C, D. A and C are alternate cube corners, while B and D are alternate cube centres. Then with a random distribution of iron and aluminium atoms, there is an equal probability of finding aluminium atoms in A, B, C or D. In the fully ordered state of FeAl all the B and D atoms will be aluminium, and the A and C atoms iron. In Fe_3Al there are in addition to the random solution, two other possibilities. Either all the aluminium may go into B or it may be distributed equally between B and D. Complete order is only attained through slow cooling. Rapid cooling of an alloy containing slightly more aluminium than Fe_3Al leaves both iron and aluminium atoms in B and D.

For other compositions and heat-treatments the proportions of iron and aluminium atoms in A, B, C, and D positions show steady changes. At the theoretical compositions FeAl, B and D positions are fully occupied by aluminium, A and C by iron. With less than this amount of aluminium, some iron moves into B and D to make up the deficiency. At still lower concentrations of aluminium the position of the aluminium atoms is more susceptible to heat treatment, the FeAl structure gradually changing over into the Fe_3Al structure as the slowly-cooled alloys vary in composition.

A remarkable example of the effect of heat-treatment is shown by he alloys of copper and aluminium to which reference has already been made. At the composition Cu_3Al the slowly-cooled alloys show the alpha plus beta structure, which is the equilibrium state for room temperature. Examination in a high-temperature camera, on the other hand, shows that the alloy is in the beta form, being body-centred cubic with copper and aluminium atoms mixed at random. On quenching to room temperature the structure is destroyed, but there is not enough time for the completion of the transformation, an intermediate metastable condition being obtained known as the B^1 phase. However, by quenching to about 400° and examining at this temperature, yet a fourth effect is observed. The body-centred cubic structure is preserved, but the alloy is no longer disordered. The structure settled down to a regular arrangement like that of Fe_3Al, but with copper instead of iron.

A modification of these results is obtained if some of the copper is replaced by manganese. It then becomes possible by quickly cooling the alloy to preserve the body-centred structure even at room temperature. If there is enough manganese present the alloy then becomes ferromagnetic. The best conditions are obtained if the composition corresponds to the formula Cu MnAl. Under these conditions all three kinds of atoms occupy regular positions in the lattice. It is interesting to compare the ferromagnetic quenched alloy with the non-magnetic slowly cooled alloy. Originally taken from the same melt these are of identical composition. The only difference lies in the arrangement of the atoms, the non-magnetic material being structurally similar to Cu_9Al_4 and Cu_5Zn_8. It is interesting to note that these later alloys are both diamagnetic, and it seems probable that, but for the presence of some iron in the maganese, the same would be true often of the non-magnetic Heusley alloy.

No reference has been made to the deformed structures, as these form a subject to themselves. There are indeed many more aspects of the subject which for lack of time must be omitted from this lecture. The subject is still expanding at such a rate, that it is impossible to give more than a short account of some of the work which is being carried out in this field.

Business Notes and News

Andrew Carnegie Research Fund

The Council of the Iron and Steel Institute are prepared to make annually a limited number of grants from the Research Fund founded by the late Mr. Andrew Carnegie in aid of metallurgical research work. The object of the scheme is not to facilitate ordinary collegiate studies, but to enable students, who had passed through a college curriculum or have been trained in industrial establishments, to conduct researches on problems of practical and scientific importance relating to the metallurgy of iron and steel and allied subjects.

The value of the grant will depend on the nature of the proposed research work, but the maximum amount granted in any one year will, as a rule, not exceed £100. The Council may, at their discretion, award a further grant in aid of any particular research work, which seems to them sufficiently meritorious to justify further assistance. In considering the allocation of grants, the Council are guided by the nature of the subjects proposed for investigation, preference being given to those which, in their judgment, appear to be of the most practical advantage to the iron and steel and allied industries.

Candidates, who must be under 35 years of age, must apply before January 10 next, on a special form to be obtained from the Secretary, Iron and Steel Institute, 28, Victoria Street, London, S.W. 1.

The Halley Motor Works

The Halley Motor Works at Yoker, Glasgow have been acquired by Messrs. Albion Motors, Ltd., for extension purposes. They, in turn, have sold the goodwill of the former business to George Cohen Sons and Company, Ltd., engineers and machinery merchants. Halley Motors supplied the first mechanically propelled fire-engine to the Glasgow Corporation in 1910 and, by a coincidence, the last vehicle to be completed in the Works was a fire-engine for the Clydebank Fire Brigade.

The business was started in 1901 by George Halley, one of the earliest pioneers of commercial motor manufacture. He began by making steam wagons and was soon producing three, four, five and even six-tonners—an enormous size for those days. By 1906 he had turned his attention to petrol vehicles and the business so prospered that by 1914 the output had increased twenty-five fold.

In the mechanical transport units of the British Expeditionary Force the " Halley " lorries did wonderful work in taking supplies and ammunition to the front, under appalling conditions. George Halley died in 1920, soon after designing the very first commercial vehicle with a six-cylinder engine.

Vancouver's Golden Jubilee

Vancouver, Canada's third largest city and the Empire's gateway to the Pacific, is preparing to celebrate its fiftieth anniversary. Its rise from a forest clearing to a world port within the space of two generations has been spectacular, and the celebrations are being planned on a corresponding scale. From May onward next year, the city will be given over to a series of celebration weeks, culminating in August in the opening of the Canada Pacific Exhibition.

The Exhibition Association has announced that, in order to mark the historic occasion, it is proposed to erect a British Empire Building to house a permanent display of British manufactures, with the object of promoting closer business relations between British Columbia, the Mother Country, and the Empire generally.

The United Kingdom has always been British Columbia's chief market, but the ships that leave Vancouver for British ports with full cargoes all too frequently return in ballast. If they could arrive at Vancouver laden with British goodsit would mean a big reduction in transportation rates both ways.

It is pointed out that goods shipped to Vancouver by way of the Panama Canal for distribution in the four Western Canadian provinces, and in the American States on the Pacific coast, enjoy the advantage not only of an all-the-year-round service by virtue of Vancouver's position as an ice-free port but also of a cheaper route than via Eastern ports ; while, by employing Vancouver as an entrepot, the markets of the Orient and Australasia can be better served.

Firms interested in the proposal are invited to communicate with the Agent General for British Columbia, British Columbia House, 1/3, Regent Street, London, S.W. 1.

Allied Art and Handicraft Exhibition

Among the many interesting exhibits at the applied art and handicraft exhibition at the new Burlington Galleries, a noteworthy feature was the remarkable results achieved from stainless steel in the hands of an artist. It seems incredible that such a stubborn metal as steel can be formed, merely by hammering the flat sheets by hand, into such beautiful things ; yet Mr. Wallis of Altrincham, Cheshire, has proved that " Staybrite " is not only easily manipulated by the hand-worker, but is a metal of great beauty when used by the artist, sensitive to the requirements of his material and one which, in colour and texture, harmonises with most modern interior decoration.

The application of this metal is known to be very wide, from large chemical vats to the most delicate surgical instruments, especially when corrosion-resisting qualities are desirable, but few people would appreciate its value for artistic work of the character exhibited. It was a revelation to see the wonderful effects obtainable when this metal is finished with a beautiful semi-polished silverlike surface and worked into beautiful forms.

Air-belt sections of two cupolas in course of transit from Birmingham to Middlesbrough, to be erected at the foundry of Stanton Ironworks. Built by the Constructional Engineering Co., Ltd., for continuous melting in connection with the manufacture of cast-iron pipes, these cupolas have an outside shell diameter of 8 ft. and will be approximately 60 ft. high.

Steel for New Zealand

Orders for £10,000 worth of steelwork for bridges have been placed on the North East Coast and South Wales for the New Zealand Railways. The material is to be shipped from Middlesborough and Newport. It is gratifying to note that the Dominion is adhering to the policy of placing all possible contracts in Great Britain.

Changes in Vickers Directorate

Vickers, Ltd., announce the following changes in the constitution of their Board of Directors and of the Boards of their Subsidiary Companies, Vickers-Armstrongs, Ltd., and English Steel Corporation, Ltd., consequent on the death of Sir Mark Webster Jenkinson, K.B.E., F.C.A., and the acquisition by Vickers, Ltd., of the whole of the share capital of Vickers-Armstrongs, Ltd. :—

The following gentlemen have been appointed to the Board of Vickers, Ltd., Major-General Sir John Humphrey Davidson, K.C.M.G., C.B., D.S.O., and Mr. F. C. Yapp. As from January 1, 1936, the Board of Directors of Vickers-Armstrongs, Ltd., will be constituted as follows : Commander Sir Charles Craven, R.N. (Chairman and Managing Director), General Sir J. F. Noel Birch, C.B.E., K.C.B., K.C.M.G. ; Sir A. George Hadcock, K.B.E., F.R.S., D.Sc. ; Mr. F. C. Yapp ; Mr. J. Callander (General Manager of the Barrow Works and Naval Yard, Newcastle-on-Tyne), and Mr. J. Reid Young, C.A. (Secretary of Vickers, Ltd.). As from January 1, 1936, Commander Sir Charles Craven, R.N., will be Chairman of English Steel Corporation, Ltd., in place of Colonel J. B. Neilson, C.M.G., and will retain his office as Managing Director. D.S.O., C.A., Mr. F. Pickworth will be a Director of English Steel Corporation, Ltd., from the same date.

MARKET PRICES

ALUMINIUM.

98/99% Purity	£100	0	0

ANTIMONY.

English	£76	10	0
Chinese	64	0	0
Crude	33	10	0

BRASS.

Solid Drawn Tubes	lb.	9¾d.
Brazed Tubes	„	11¼d.
Rods Drawn	„	8⅝d.
Wire	„	7¾d.
*Extruded Brass Bars	„	4¾d.

COPPER.

Standard Cash	£35	0	0
Electrolytic	39	5	0
Best Selected	38	10	0
Tough	38	0	0
Sheets	68	0	0
Wire Bars	40	5	0
Ingot Bars	40	5	0
Solid Drawn Tubes	lb.	1	½d.
Brazed Tubes	„	10½d.	

FERRO ALLOYS.

†Tungsten Metal Powder	lb.	0	3	3
‡Ferro Tungsten	„	0	3	0
NOMINAL: Ferro Chrome, 60-70% Chr. Basis 60% Chr. 2-ton lots or up. 2–4% Carbon, scale 11/- per unit	ton	29	15	0
NOMINAL: 4–6% Carbon, scale 7/- per unit	„	22	7	6
NOMINAL: 6–8% Carbon, scale 7/- per unit	„	21	12	0
NOMINAL: 8–10% Carbon, scale 7/- per unit	„	21	12	0
§Ferro Chrome, Specially Refined, broken in small pieces for Crucible Steelwork. Quantities of 1 ton or over. Basis 60% Ch. Guar. max. 2% Carbon, scale 11/0 per unit	„	33	10	0
Guar. max. 1% Carbon, scale 12/6 per unit	„	36	5	0
§Guar. max. 0·7% Carbon, scale 12/6 per unit	„	37	5	0
‡Manganese Metal 97–98% Mn.	lb.	0	1	2
‡Metallic Chromium	„	0	2	5
§ Ferro-Vanadium 25–50%	„	0	12	8
§ Spiegel, 18–20%	ton	7	10	0
Ferro Silicon— Basis 10%, scale 3/- per unit	ton	6	5	0
20/30% basis 25%, scale 3/6 per unit	„	8	17	6
45/50% basis 45%, scale 5/- per unit	„	12	5	0
70/80% basis 75%, scale 7/- per unit	„	17	17	6
90/95% basis 90%, scale 10/- per unit	„	28	17	6
§ Silico Manganese 65/75% Mn., basis 65% Mn.	„	12	17	6
§ Ferro-Carbon Titanium, 15/18% Ti	lb.	0	0	4½
Ferro Phosphorus, 20–25%	ton	20	0	0
§ Ferro-Molybdenum, Molyte	lb.	0	4	6
§ Calcium Molybdate	„	0	4	2

FUELS.

Foundry Coke— S. Wales	—	1	5	0
Scotland	—	1	8	0
Durham	0 19 0 to	1	2	0
Furnace Coke— Scotland	—	1	5	0
S. Wales	—	1	0	0
Durham	—	0	17	6

GUN METAL.

*Admiralty Gunmetal Ingots (88 : 10 : 2)	£56	10	0
*Commercial Ingots	42	0	0
*Gunmetal Bars, Tank brand, 1 in. dia. and upwards	lb.	0	0	9
*Cored Bars	„	0	0	11

LEAD.

Soft Foreign	£17	19	0
English	20	0	0

MANUFACTURED IRON.

Scotland— Crown Bars, Best	£10	5	0
N.E. Coast— Rivets	10	10	0
Best Bars	10	2	6
Common Bars	9	5	0
Lancashire— Crown Bars	9	12	6
Hoops £10 10 0 to	12	0	0
Midlands— Crown Bars	9	12	6
Marked Bars	12	0	0
Unmarked Bars from	7	5	0
Nut and Bolt Bars £7 10 0 to	8	0	0
Gas Strip	10	12	6
S. Yorks— Best Bars	10	15	0
Hoops £10 10 0 to	12	0	0

PHOSPHOR BRONZE.

*Bars, "Tank" brand, 1 in. dia. and upwards—Solid	lb.	9½d.
*Cored Bars	„	11½d.
†Strip	„	11½d.
†Sheet to 10 W.G.	„	11½d.
†Wire	„	1/0½
†Rods	„	11½d.
†Tubes	„	1/1½
†Castings	„	1/-

†10% Phos. Cop. £30 above B.S.
†15% Phos. Cop. £35 above B.S.
†Phos. Tin (5%) £30 above English Ingots.

PIG IRON.

Scotland— Hematite M/Nos.	£3	13	6
Foundry No. 1	3	16	6
„ No. 3	3	13	0
N.E. Coast— Hematite No. 1	3	11	0
Foundry No. 1	3	12	6
„ No. 3	3	10	0
„ No. 4	3	9	0
Silicon Iron	3	10	0
Forge	3	9	0
Midlands— N. Staffs Forge No. 4	3	11	0
„ Foundry No. 3	3	15	0
Northants— Foundry No. 1	3	15	6
Forge No. 4	3	8	6
Foundry No. 3	3	12	6
Derbyshire Forge	3	11	0
„ Foundry No. 1	3	18	0
„ Foundry No. 3	3	15	0
West Coast Hematite	4	6	0
East „ „	3	11	0

SWEDISH CHARCOAL IRON AND STEEL.

Pig Iron Kr. 105
Billets Kr. 240-310 £12 7 6-£16 0 0
Wire Rods Kr. 290-340 £15 0 0-£17 10 0
Rolled Bars (dead soft) Kr. 200-220 £10 6 0-£11 7 0
Rolled Charcoal Iron Bars Kr. 290 15 0 0
All per English ton. f.o.b. Gothenburg.
Converted at £1 = Kr. 19.40 approx.

SCRAP METAL.

Copper Clean	£29	0	0
„ Brazery	26	0	0
„ Wire		—	
Brass	19	0	0
Gun Metal	27	0	0
Zinc	9	0	0
Aluminium Cuttings	72	0	0
Lead	15	15	0
Heavy Steel— S. Wales	2	17	6
Scotland	2	10	0
Cleveland	2	12	0
Cast Iron— Midlands	2	7	6
S. Wales	2	14	0
Cleveland	2	12	0
Steel Turnings— Cleveland	1	17	6
Midlands	1	15	6
Cast Iron Borings— Cleveland	1	7	6
Scotland	1	17	6

SPELTER.

G.O.B. Official		—	
Hard	£12	0	0
English	16	0	0
India	13	10	0
Re-melted	14	0	0

STEEL.

Ship, Bridge, and Tank Plates Scotland	£8	15	0
North-East Coast	8	15	0
Midlands	8	17	6
Boiler Plates (Land), Scotland	8	10	0
„ „ (Marine) „		—	
„ „ (Land), N.E. Coast	8	10	0
„ „ (Marine) „	8	17	6
Angles, Scotland	8	7	6
„ North-East Coast	8	7	6
„ Midlands	8	7	6
Joists	8	15	0
Heavy Rails	8	10	0
Fishplates	12	10	0
Light Rails £8 10 0 to	8	15	0
Sheffield— Siemens Acid Billets	9	2	6
Hard Basic £6 17 6 to	7	2	6
Medium Basic £6 12 6 and	7	0	0
Soft Basic	5	10	0
Hoops £9 10 0 to	9	15	0
Manchester Hoops £9 0 0 to	10	0	0
Scotland, Sheets 24 B.G.	10	10	0

HIGH SPEED TOOL STEEL.

Finished Bars 14% Tungsten	lb.	2/-
Finished Bars 18% Tungsten	„	2/9
Extras		
Round and Squares, ¼ in. to ½ in.	„	3d.
Under ½ in. to 5/16 in.	„	1/-
Round and Squares 3 in.	„	4d.
Flats under 1 in. × ⅛ in.	„	3d.
„ „ ½ in. × ⅛ in.	„	1/-

TIN.

Standard Cash	£219	0	0
English	219	5	0
Australian	219	0	0
Eastern	216	5	0

Tin Plates I.C. 20 × 14 box 18/9

ZINC.

English Sheets	£23	12	6
Rods	28	10	0
Battery Plates		—	
Boiler Plates		—	

*McKechnie Brothers, Ltd. Dec. 12 † C. Clifford & Son, Ltd., Dec. 12 ‡ Murex Limited, Dec. 12

Subject to Market fluctuations. Buyers are advised to send inquiries for current prices.

§ Prices ex warehouse, Dec. 12